Investigation into Mechanical and Tribological Properties of *Ipomoea carnea* Reinforced Epoxy Composite

A thesis submitted in partial fulfilment of the requirement for the degree of

Master of Technology
In
Mechanical Engineering
(Specialisation-Machine Design and Analysis)

Submitted to

National Institute of Technology, Rourkela

By

Kamal Kumar Basumatary
(Roll no. 211me1375)

Department of Mechanical Engineering
National Institute of Technology
Rourkela-769008
India
June-2013

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Under the guidance of

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Rourkela-769008 (Orissa), INDIA

CERTIFICATE

This is to certify that the thesis entitled "**INVESTIGATION INTO MECHANICAL AND TRIBOLOGICAL PROPERTIES OF *IPOMOEA CARNEA* REINFORCED EPOXY COMPOSITE"** submitted to the National Institute of Technology, Rourkela by **Kamal Kumar Basumatary**, Roll No. **211ME1375** for the award of the Master of Technology in Mechanical Engineering with specialization in **Machine Design and Analysis** is a record of bonafide research work carried out by him under my supervision and guidance. The results presented in this thesis has not been, to the best of my knowledge, submitted to any other University or Institute for the award of any degree or diploma.

The thesis, in my opinion, has reached the standards fulfilling the requirement for the award of **Master of Technology** in accordance with regulations of the Institute.

Place:

Date: 3rd-June-2013

(Dr. S. K. Acharya)
Professor
Department of Mechanical Engineering
NIT Rourkela

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Date: - 3rd-June-2013 **(Kamal Kumar Basumatary)**

Abstract

Growing environmental concern and regulations are shifting the designer's choice from synthetic fiber reinforced composite and plastics to natural fiber composites. Polymeric materials reinforced with synthetic fibers such as glass, carbon, and aramid provide advantages of high stiffness and strength to weight ratio compared to conventional construction material like wood, concrete and steel. The promising application of natural fibers in composite applications is packaging, decking, interior panels and furniture. Due to its high specific strength and modulus natural fibers are emerging as promising reinforcement material for fiber reinforced polymer (FRP) composites. Numerous possible material combinations, unique self-lubrication capabilities and low operating noise make the FRP composites a potentially better material over conventional metallic materials for tribological applications.

Observing the tremendous advantages and opportunity of natural fibers there is a need to further explore the possibility of new fibers to be used as reinforcement in polymer composites for tribological applications. *Ipomoea carnea*, locally called as "Amari" is one such natural resource found abundantly in many parts of India, whose potential as fiber reinforcement in polymer composite has not been explored till date. *Ipomoea carnea* is a gregariously growing short shrub available all over the world. The plant is native of South America and was introduced in to India as an ornamental plant. Cellulose content of this shrub is over 55% and lignin content is about 17% which indicates it is a fibrous material and can be used as filler for making light weight polymer composite which provides an effective means of utilization of a large quantity of this diffuse shrub. Literature indicates that no significant work has been done on this shrub other than its stems are used for developing housing element in rural India without any pre-treatment resulting non-durable structure. Hence in this present work an attempt has been made to prepare and study the mechanical and abrasive wear behaviour of *Ipomoea carnea* reinforced epoxy composite, with different concentration of particulates.

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Chapter 1

INTRODUCTION

CHAPTER-1

1.1 BACKGROUND

The wonder materials Composites, with light weight, high strength to weight ratio and stiffness properties has replaced most of the metal and alloys in recent times. Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. Generally, fibers are the principal load carrying members, while the matrix keeps them at the desired location and orientation, acts as a load transfer medium between the fibers, and protects them from environmental damages. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement also affect the properties.

Industries today are under tremendous pressure to design ecologically friendly materials for their products. This is because of growing environmental awareness and new rules and regulations that are binding on industries. As a result researcher's choices are shifting from synthetic fiber reinforced composite and plastics to natural fiber composites. Polymeric materials reinforced with synthetic fibers such as glass, carbon and aramid provide advantages of high stiffness and strength to weight ratio compared to conventional construction material like wood, concrete and steel. Despite its several advantages, the use of natural fiber application in polymeric composites is increasing day by day. A substantial increase in the agricultural by products and wastes of different types has attracted many researchers to develop and characterize new and low cost materials from renewable local resources.

1.2 NATURAL FIBERS: Initiative in product development

Natural fibers can be obtained from natural resources such as plants, animals or minerals. With the increase of global crisis and ecological risk, the unique advantages of plant fibers such as abundant, nontoxic, non-irritation of skin, eyes or respiratory system, non-corrosive property, plant-based fibre reinforced polymer composites has lately received increasing attention both from academia and by industries.

It can be brought to notice that compared to most synthetic fibers, natural fibers are has emerged to be more environment friendly and appeared realistic alternative for the following reasons:

(1) Natural fiber production has consumed of non-renewable energy lesser than synthetic fiber and thus lesser pollution emissions.
(2) The higher volume fraction of natural fiber than synthetic fiber for equivalent performance has decreased the volume and weight of base synthetic polymer matrix, which decreases the energy use and emissions in production of polymer.
(3) The lower weight (20-30 wt. %) and higher volume of natural fiber compared to synthetic fiber has improved the fuel efficiency and reduced emission in the use phase(auto applications)
(4) The incinerated of natural fiber composite direct to positive carbon credit and enhanced the net effects on air emissions and energy recovery due to the lower mass of base polymer in natural fiber composite.
(5) Natural fiber composites are claim to offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery and end of life bio degradability of components.
(6) Natural fibers have lower cost (US$ 200-1000/ton) and energy to produce (4GJ/ton) whereas glass cost US$ 1200-1800/ton and energy to produce is 30GJ and carbon cost US$ 12500/ton and energy to produce it is 130GJ.

Such superior advantages are important driver of increased future use of natural fiber composite in various applications and under different loading.

1.2.1. Chemical composition of natural fibers

The proportions of constituents of any natural fiber vary with origin, area of production, variety and maturation of plant. The major constituent of a fully developed natural fiber cell walls are cellulose, hemicellulose, lignin and pectin. These hydroxyl-containing polymers are distributed throughout the fiber wall [1].

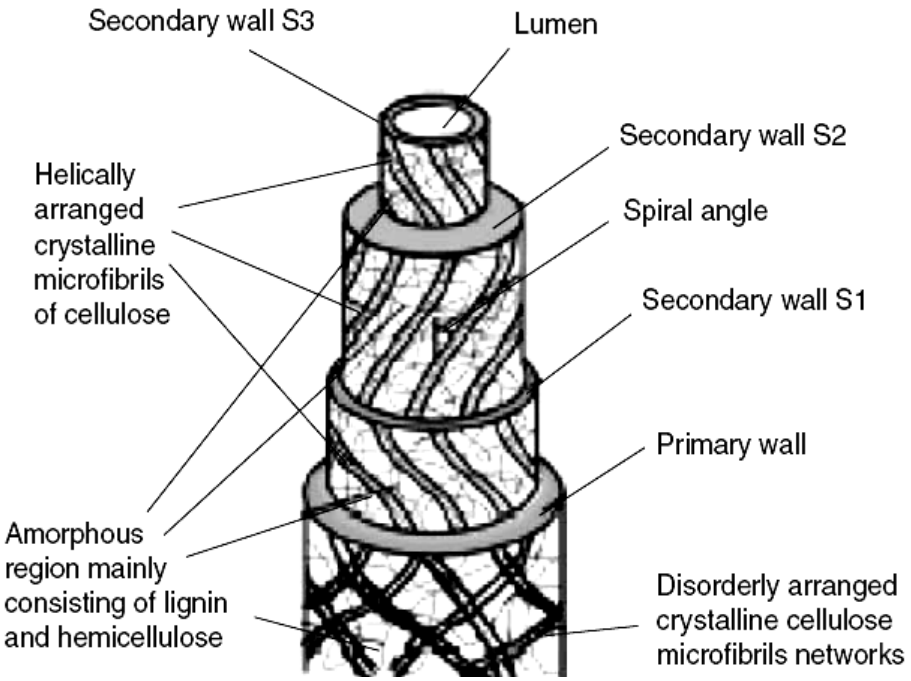

Fig 1.1: Structure of an elementary plant fiber (cell)

a) Cellulose

The long thin crystalline micro-fibrils in the secondary cell wall are made of cellulose. It is the reinforcing material and is responsible for the high mechanical strength of fibers. It consists of a linear polymer of D-anhydro glucose units where two adjacent glucose units are linked together by β-1, 4-glycosidic linkages with elimination of one water molecule between their -OH groups at carbon atoms 1 and 4. Chemically, cellulose is defined as a highly crystalline segment alternating with regions of non-crystalline or amorphous cellulose [2, 3].

The glucose monomers in cellulose form hydrogen bonds both within its own chain (intra molecular) forming fibrils and with neighbouring chains (intermolecular), forming micro fibrils. These hydrogen bonds lead to formation of a linear crystalline structure with high rigidity and strength. The amorphous cellulose regions have a lower frequency of intermolecular hydrogen bonding, thus exposing reactive intermolecular -OH groups to be bonded with water molecules. Amorphous cellulose can therefore be considered as hydrophilic in nature due to their tendency to bond with water. On the other hand, very few accessible intermolecular –OH are available in crystalline cellulose and it is far less hydrophilic than amorphous cellulose. Crystalline micro-fibrils have tightly packed cellulose chains within the fibrils, with accessible –OH groups present on the surface of the structure.

Only very strong acids and alkalis can penetrate and modify the crystalline lattice of cellulose.

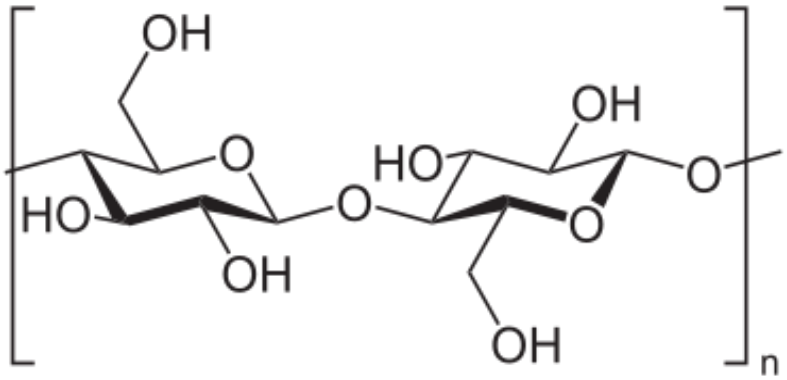

Fig 1.2: Structure of cellulose

b) Hemicelluloses

Hemicelluloses differ from cellulose in three different ways. Firstly, unlike cellulose (containing only 1, 4-β-D-glucopyranose units) they contain several different sugar units. Secondly, they exhibit a considerable degree of chain branching, whereas cellulose is a linear polymer. Thirdly, the degree of polymerization of native cellulose is ten to hundred times higher than that of hemicelluloses. Unlike cellulose, the constituents of hemicelluloses differ from plant to plant. Hemicelluloses contain substituents like acetyl (-COCH3) groups and glucoronic acid. By attaching ferulic acid and p-coumaric residues, hemicelluloses can form covalent bonds to lignin [4]. Due to this linking ability of hemicelluloses, degradation of it leads to disintegration of the fibers into cellulose micro-fibrils resulting in lower fiber bundle strength [5].

c) Lignin

Lignin increases the compression strength of plant fibers by gluing the fibers together to form a stiff structure, making it possible for trees of 100 meters to remain upright. Lignin is essentially a disordered, polyaromatic, and cross-linked polymer arising from the free radical polymerizations of two or three monomers structurally related to phenyl-propane [6]. Free radical coupling of the lignin monomers gives rise to a very condensed, reticulated, and cross-linked structure. The lignin matrix is therefore analogous to a thermoset polymer in conventional polymer terminology. The dissolution of lignin using chemicals aids fiber

separation. When exposed to ultraviolet light, lignin undergoes photochemical degradation [7]. The lignin seems to act like a matrix material within the fibers, making stress transfer on a micro-fibril scale and single fiber scale possible.

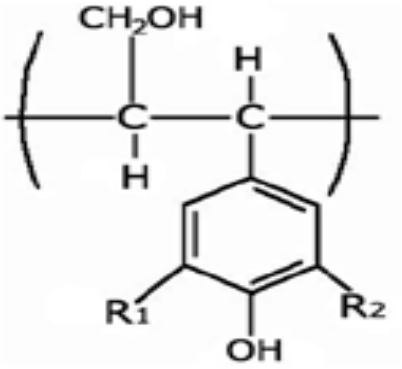

Fig 1.2: Structure of lignin

Studies of fibre composition and morphology reveals that cellulose content and micro-fibril angle tend to control the mechanical properties of cellulosic fibres.

1.3 POLYMER COMPOSITE

Polymers are structurally much more complex than metals or ceramic. They are cheap and can be easily processed. On the other hand, polymers have lower strength and modulus and lower temperature use limits. Prolonged exposure to ultraviolet light and to some solvents can cause the degradation of polymer properties. Because of predominantly covalent bonding, polymers are generally poor conductors of heat and electricity. Polymers, however, are generally more resistant to chemicals than are metals. Structurally, polymers are giant chainlike molecules (hence the name macromolecules) with covalently bonded carbon atoms forming the backbone of the chain. The process of forming large molecules from small ones is called polymerization; that is, polymerization is the process of joining many monomers, the basic building blocks, together to form polymer. Polymers used to manufacture advanced PMCs are of two basic types, thermoset and thermoplastics resins.

a) Thermoset resins:

Thermoset resins dominate the advanced composites industry today, while thermoplastics have only a minor role. It requires addition of a curing agent or hardener and impregnation onto a reinforcing material, followed by a curing step to produce a cured or finished part.

b) Thermoplastic resins:

Thermoplastics resins require only heat and pressure to form the finished part. Unlike the thermoset resins, the thermoplastics resins can usually be reheated and reformed into another shape, if desired. Common examples of thermoplastics resins are polyethylene, polystyrene, nylon, polycarbonate, polysulfone, polyphenylenesulfine etc. Polyamides, Polyimide, PEEK are relatively newcomers to the composite industry and are used for high temperature applications. These resins have better thermal stability and flame resistance than the epoxy resins. Polyamide based composites have excellent retention of strength in how-wet environment but they are brittle and have a very low elongation at break.

The matrix material used for the present investigation is epoxy resin with the functional group oxirane, a three-membered strained ring containing oxygen.

Epoxy resin is a widely used polymer matrix for advanced composites where good stiffness, dimensional stability and chemical resistance are required. They are relatively low molecular weight monomers with low shrinkage during cure. They can be partially cured and stored in that state. The cured epoxy resins have high chemical and corrosion resistance, good mechanical thermal properties. However, they are more expensive compared to polyester resin. The second of the essential ingredients of an advanced composite system is the curing agent or hardener. These compounds are very important because they control the reaction rate and determine the performance characteristics of the finished part. Since these compounds act as catalysts for the reaction, they must contain active sites on their molecules. A wide range of starting materials can be used for the preparation of epoxy resins thereby providing a variety of resins with controllable high performance characteristics. These resins generally are prepared by reacting to a polyfunctional amine or phenol with epichlorohydrin in the presence of a strong base. The most commercially available diglycidyl ether of bisphenol-A (DGEBA), (Fig-1.3), is characterized by epoxy equivalent weight, which can be determined either by titration or quantitative infrared spectroscopy. The presence of glycidyl units in these resins enhances the processability but reduces thermal resistance.

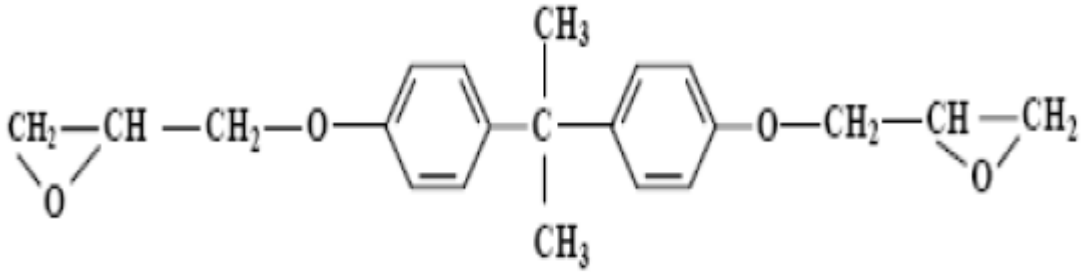

Figure-1.3 Chemical structure of DGEBA

The mechanical properties of this polymer matrix, such as the strength, modulus and toughness of the epoxy resins may not be sufficient for some end-use applications. It is therefore desirable to modify the polymer matrix to achieve such purposes. The addition of fillers to polymer matrix is a fast and cheap method to modify the properties of the base materials. Addition of various fillers with different shapes, particle size and different sources into the epoxy matrix may result in different microstructures and have different effects on the properties of the polymer composites.

1.4 NATURAL FIBER

There are many potential natural resources which India has in abundance. Most of them come from forest and agriculture. Observing the tremendous advantages and opportunity of natural fibers there is a need to further explore the possibility of new fibers to be used as reinforcement in polymer composites for mechanical and tribological applications. *Ipomoea carnea*, locally called as "Amari" is one such natural resource found abundantly in many parts of India. It is an intriguing plant belonging to family Convolvulaceae. Although it was native of South America, it was introduced in India as an ornamental plant.

It is large diffuse and short shrub found around ponds, puddles and wet places in most parts of India. This plant spreads vegetatively by stems which are capable of rooting within a few days. The plant is propagated by cuttings, and it stands pruning well. It produces dense foliage and flowers practically throughout the year, except during the cold months. It is drought resistant and can improve the soil as compost in the dry land areas. It is used as green manure crop in Madras, South India *Ipomoea carnea* can be raised both under rain fed and irrigated conditions. Therefore it can safely be used on waste lands and on river sides for controlling soil erosion. Under rain fed conditions, a border crop, 1.6 km in length, gave

about 340 kN of green matter in one year in six cuttings; under irrigated conditions the yield can be double. This suggests that quantities of the order of millions of tonnes can be easily grown in areas of the order of hundred square kilometres which are readily available. The farmers use it as ornamental and hedge plant along the banks of irrigation and drainage canals. The rapid growth rate, spread, and adaptability from aquatic to xerophytic habitats indicate that this plant may potentially become an ecological disaster. The stem is thick and develops into a solid trunk over several years with many branches from base. The leaves are light green and heart shaped. The fresh stem is somewhat flexible, but the dry one breaks with a fibrous fracture exposing a whitish green interior, with hollow internodes and solid nodes. The internodes measure 3.5-6.0 cm in length. Table 1.1 shows the chemical composition of Ipomoea carnea stems as reported by Navin Chand[8].

Table 1.1: Chemical composition of *Ipomoea carnea* chips

SL. No	**Components**	**% composition**
1	Cellulose	57.73
2	Lignin	16.59
3	Pentosan	17.30
4	Ash	6.45
5	Silica	0.16

This species is renowned as a weed all over the world and it dominates over the accompanying species. Throughout history scientist and researcher have striven hard to find ways of destroying this weed. But this weed has continued to challenge researchers by defying destruction and control.

Visualizing the luxuriant growth and vigorous survival of this weed, researchers worldwide are trying to find out the potential economic value for its utilization into value added products and effective method for its management. Therefore the main objective of this work is to prepare a Polymer Matrix Composite (PMC) using epoxy resin as matrix material and *Ipomoea carnea* fiber as reinforcement besides its traditional use.

Fig 1.4 Photographs of *Ipomoea carnea* plant

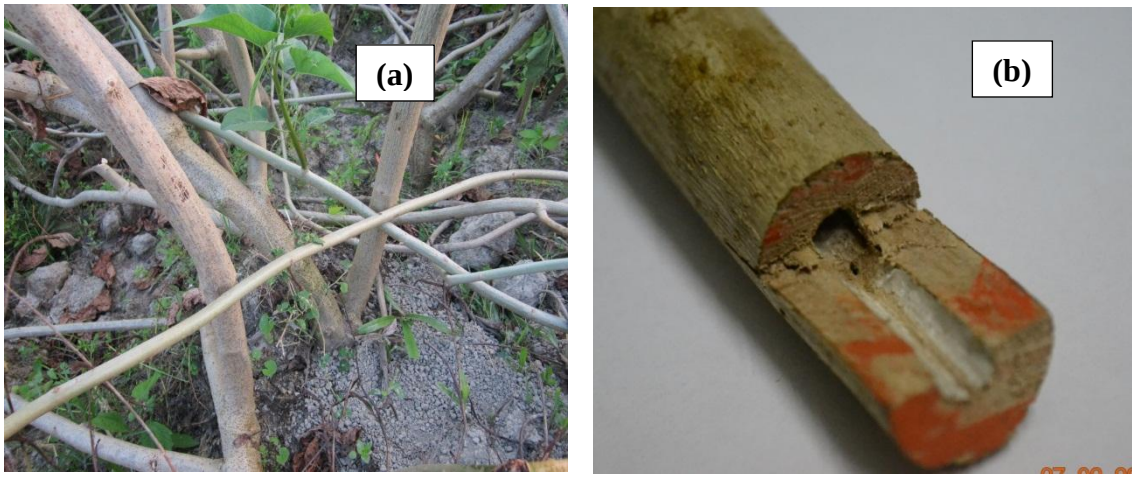

Fig 1.5 (a) Stem of *Ipomoea carnea* (b) Cross section of *Ipomoea carnea* stem

Chapter 2

LITERATURE SURVEY

CHAPTER 2

2.1 Literature survey

In the recent years, natural fibers such as hemp, flax, jute, linen, kenaf, oil palm and bamboo have been drawn considerable attention in numerous applications, e.g. automobiles, furniture, packing and construction. This is due to their superior advantages over synthetic fibers in terms of relatively low cost, low weight, less damage in processing equipment, improved surface finish of moulded parts composite, good relative mechanical properties, abundant and renewable resources.

From mechanical point of view, natural fibres may enhance mechanical properties of polymers with some considerations and improvement to the surface characteristics natural fibre. There are several factors related to the natural fibres which influence the performance of the composites such as the interfacial adhesion, the orientation, the strength, physical properties, etc. The mechanical efficiency of the fibre-reinforced polymer composites depends on the fibre–matrix interface and the ability to transfer stress from the matrix to fibre as reported by many researchers, [9–20]. Moisture absorption, impurities, orientation, volume fraction and physical properties of natural fibres play constitutive role to determine the mechanical properties of fibre polymer composites. In most cases, natural fibres reinforced polymer composites exhibit better mechanical properties than the pure matrix. In other words, the use of natural fibres as reinforcement for polymeric composites introduces positive effect on the mechanical behaviour of polymers. Addition of jute fibres [21] to poly(lactic acid) (PLA) showed 75.8% enhancement to the tensile strength of PLA while flax fibres exhibited negative impact, i.e. decrease the tensile strength of composite by 16%. On other hand, kenaf [22], hemp [23], and cotton [24] improved the tensile strength of PP composite. Tensile strength of epoxy improved with the addition of jute fibres [25] but the jute fibres deteriorated the compressive strength. Meanwhile, jute enhanced all the mechanical properties of polyester composites [25]. Jute/polyester composite has showed the maximum improvement in tensile strength by 121% compared to pure polyester.

Most of the industrial and manufacturing parts are exposed to tribological loadings such as adhesive, abrasive, etc. in their service. Therefore, tribological performance of materials becomes an essential element to be considered in design mechanical parts. In other

words, understanding the tribological behaviour of natural fibre/polymer composites has an equal role to be considered with the mechanical properties of those materials [26]. Nevertheless, less work has is found on the effects of natural fibres on the tribo-performance of polymeric composites in the literature. Some studies have been emphasized that the tribology behaviour of composite polymers based on the natural fiber is not intrinsic behaviour and it strongly depend on many processing's parameters such as operating parameters, characteristics of polymer martial, physical and interfacial adhesion properties of fibre, additives and contact condition. Few works have been attempted to investigate the tribological behaviour of polymeric composites based on natural fibres such as Kenaf [27], Oil palm [28], Sisal [29], Cotton [30], Jute [31], Betelnut [26], Bamboo [32]. Polymers have displayed different tribology behaviours with different type of natural fibres. In general, one can say that after certain sliding distance, steady state can be achieved. However, in the running period (first stage of the sliding), there is difference in the wear behaviour of the composites. In some cases such as polyester [33], chopped glass/polyester [34], cotton/polyester [30], and kenaf/epoxy [27], the composite showed low specific wear rate and an increase in the steady state stage which is due to the adaption period of the two rubbed surfaces in the running stage. Moreover, in those works, it has been reported that the film generated on the counterface became smoother at the steady state than the running in. However, in coir/polyester [33], sisal/polyester [29], betelnut/polyester [26] and bamboo/epoxy [32] showed the opposite, i.e. high specific wear rate at the first stage and then reduced at the steady state due to the smoothening process occurred on both rubbed surface. From that, it can be said that the characteristics of generated film on the counterface is the main key in determining the wear behaviour of the composite.

For the frictional behaviour of those composites, there are four catrogery of frictional trends. In [35, 29, 32], there is increase in the friction coefficient at the running in stage and then followed by the steady state. This indicates the stability of the rubbed surface characteristics. In [28, 32, 33], there is reduction in the friction coefficient in the steady stage compared to the running in, and this is due the smooth film transfer generated in on the counter-face and its high stability. On the other hand, [27, 26, 28, 31] showed fluctuated and increase in the friction coefficient value which represent the instability of the rubbed surface characteristics and modifications took place during the sliding process. In another example [29], cotton/polyester composites showed very high friction coefficient with low specific wear rate. In bearing applications, it is desired to have a low friction coefficient with low

specific wear rate. Therefore, it is suggested to reduce the friction coefficient of natural fibre/polymer composite with the addition of solid lubricants and/or use the designed components in lubricant conditions.

Hence existing literature available on natural fiber composite has put up a conclusion that combining plant natural fibers with polymer matrices results in the improvement of mechanical and tribological properties of composite compared to the matrix material. Observing the tremendous advantages and opportunity of natural fibers there is a need to further explore the possibility of new fiber to be used as reinforcement in polymer matrix.

Ipomoea carnea is a gregariously growing short shrub available all over the world, whose potential as fiber reinforcement in polymer composite has not been explored till date. Thus the priority of this work is to prepare a composite using *Ipomoea carnea* particulate as reinforcement material in polymer matrix. However literatures on *Ipomoea carnea* in engineering fields are limited.

2.2 Literature on *Ipomoea carnea*

K.H. Shaltout et al [36] in his second article about the review of Egyptian woody perennials has provided an overall review of the literature dealt with *Ipomoea carnea* population, depicting the ecological conditions of its habitats, evaluating its adaptability to different environmental conditions, identifying the gaps in the existing information, and focusing the attention of the biologists for filling these gaps.

Khalid et al [37] studied the anti-inflammatory activity of aqueous extracts of *Ipomoea carnea* leaves and found that the aqueous extract of *Ipomoea carnea* leaves possesses anti-inflammatory property with the dose dependent effect carried out on experimental model. Between the two doses studied, aqueous extract of *Ipomoea carnea* at a dose of 500mg/kg was found to possess better anti-inflammatory activity as compared to Etoricoxib. However, further phytochemical studies are needed to isolate the active compound(s) responsible for the pharmacological activities.

It is described to have stimulatory allopathic effects. Its roots are boiled to use as laxative and to provoke menstruation. It was used as a treatment for skin disease by traditional healers. The milky juice of plant has been used for the treatment of leucoderma and other related skin diseases. It has depressant effect on central nervous system. Also shows muscle relaxant property [38].

Nandkumar et al [39] also explored its paper making properties. The reactive group of the lignin of *Ipomoea carnea* upon investigation was found to be almost similar to other species, which indicated that it contains all those features of other hard wood and soft wood lignin for paper making process.

Dutt et al [40] reported that a proper blend of *Ipomoea carnea* and Cannabis *sativa* can produce a stronger paper while the former acts as brightness improver. Thus it can be used as substitute to softwood for soda pulping. His studies revealed that high calorific value spent liquor of *I. carnea* and *C. sativa* with very low silica content is advantageous factor towards energy conservation.

Konwer et al[41] after considering the yield, volatile matter content, fixed carbon content and calorific values of charcoals produced from *I. carnea*, concluded that this harmful weed showed good potentiality as the raw material for production of charcoal. However, as the density of the charcoal was found to be low, the charcoal fines need to be converted to solid fuel to improve its combustion properties.

Frey et al [42] reported the use of entire *Ipomoea carnea* sub sp. *fistulosa* as a raw material for paper-bag production. He reported a rare use of dried stem material as fire- wood in Rajasthan, because of its yellow flame.

Deshmukh et al [43] studied the Co-utilization *Ipomoea carnea* along with distillery waste for biogas production. In general, *Ipomoea carnea* showed best results alone as well as in combination with distillery waste. Use of this weed and distillery waste can be made to supplement conventional substrate like dung to augment the biogas production. The high cellulose and volatile solid content of dried stem material is responsible for its successful bio gasification [44].

In another work Navin Chand et al [8] have successfully coated its stem with creosote, cashewnut shell liquid and copper. Its stem was found to have low density (0.25-0.32 gm/cm^3) whereas its tensile strength ranging between 15.25MN/m^2 and flexural strength of the order of 100MN/m^2. Flexural strength was also found to decrease with increase of stem diameter. The powder of *Ipomoea carnea* was found to be stable up to nearly 200°C, above which it shows signs of degradation. *Ipomoea camea* chips, and its powder mix and bond readily with polyester resin, cement and mud.

Michael et al [45] investigation on zinc chloride activated *Ipomoea carnea* resulted effective adsorbent for the removal of copper from synthetic waste water. The increase in micro pores increased the adsorption percentage of copper and was found to be maximum at its natural pH.

Available literature on *Ipomoea carnea*, on its suitability in various engineering fields are negligible. Therefore in the present work an attempt has been made to study the mechanical and abrasive properties of the *Ipomoea carnea* reinforced composite.

Chapter 3

MECHANICAL PROPERTIES OF *IPOMOEA CARNEA* PARTICULATE REINFORCED EPOXY COMPOSITE

CHAPTER 3

3. 1 MATERIALS USED

The raw materials used for the present work are

1. *Ipomoea carnea* powder
2. Epoxy resin
3. Hardener

3.1.1 *Ipomoea carnea* powder

Ipomoea carnea stem was obtained locally. The outer skin layer was scraped out with the help of scissor without damaging the fiber surface. Then it was split into two halves. The inner portion was a hollow structure filled with spongy mass. The spongy mass from the hollow structure was removed and allowed to dry for one day in room temperature. The stem was then chopped into short pieces and was then dried in an oven at 60°C for 4 hours. The chopped pieces were then grinded into fine powder using ball bill. The collected powder was sieved using a sieve shaker. Separate sieve mesh sizes were used to obtain a distribution of particle sizes resulting from the crushing. Table 3.1 shows the particle distribution according to their sizes. The particle size chosen for the experiment was 100 microns due to its highest weight percentage among all sizes.

Table 3.1: Particle size

Sample	Size range - micron size	Size range + micron size	Weight (grams) approx.	Weight %
1	------	70	20	20
2	70	100	40	40
3	100	120	22	22
4	120	200	10	10
5	200	400	8	8
Total			100	

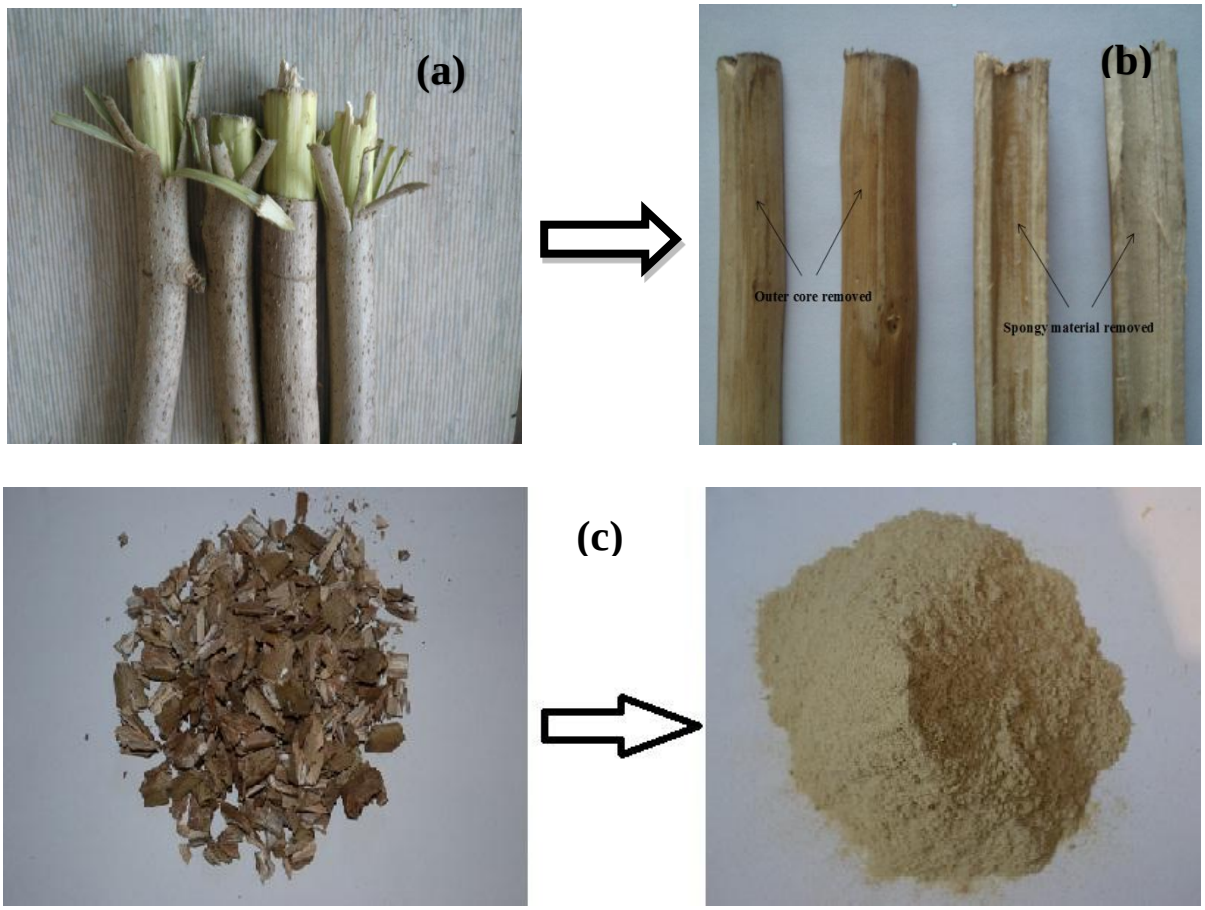

Fig 3.1(a), (b), (c): *Ipomoea carnea* fiber and particulate

3.1.2 Epoxy Resin

The type of epoxy resin used in the present investigation is Araldite LY-556 (Bisphinol-A-Diglycidyl-Ether) which chemically belongs to epoxide family. The following are the notable properties of the matrix.

- Excellent bonding with different materials.
- Highly inert to chemical and atmospheric attack.
- Great dimensional stability.
- Low internal stresses.
- Good mechanical and electrical properties compared to other thermoset plastics.
- Nontoxic, Odourless, tasteless and bio degradable.
- Insignificant shrinkage.

3.1.3 Hardener

The hardener with IUPAC name NNO-Bis (2aminoethylethane-1,2diamin) also designated as HY 951 has been used with epoxy matrix in 10:1 ratio. It is an aliphatic primary amines which has a viscosity of 10-20 MPa at 25°C.

3.2 COMPOSITE FABRICATION

A Per-pex sheet mould of dimension 140×60×4 mm was used for casting the composite sheet. The usual hand lay-up technique was used for preparation of the samples. For different weight fraction of fibers, the calculated amount of epoxy resin and hardener (ratio of 10:1 by weight) was thoroughly mixed with gentle stirring to minimize air entrapment. Different doses of particulates (10, 20, 30 and 40 wt %) were added separately in the above mixture and stirred for 10 minutes using a glass rod to obtain uniform dispersion of particulates. The mixture was then poured into the prepared mould. Before pouring the mould was coated with release agents. Pressure was then applied from the top and the mould was allowed to cure at room temperature for 72 hrs. During application of pressure a small amount of mixture of epoxy and hardener was squeezed out. Care has been taken to consider this loss during manufacturing of composite sheets. After 72 hours the samples were taken out from the mould, cut in to different sizes and shape, and kept in an air tight container for further experimentation.

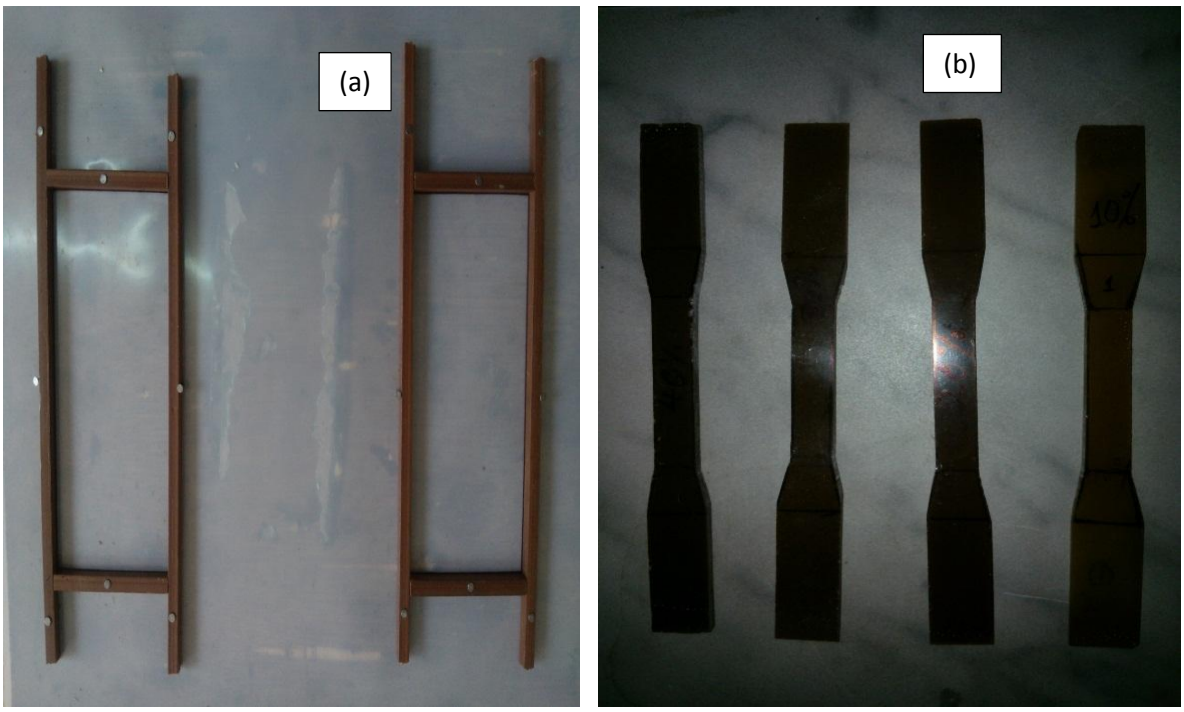

Figure-3.2 (a) Mould (b) Specimen for Tensile

3.3. CHARACTERIZATION OF THE COMPOSITES

3.3.1 Density

The density of composite materials in terms of volume fraction is found out from the following equation (1).

$$\rho_r = \frac{w_0}{(w_0)+(w_a-w_b)} \quad (1)$$

Where "ρ_r" represents relative density of the composite, w_0 represents the weight of the sample, w_a represents the weight of the bottle + kerosene, w_b represents the weight of the bottle + kerosene + sample.

$$\rho_{ce} = \rho_r * \text{density of kerosene}$$

The theoretical density of composite materials in terms of weight fraction is found out from the following equation.

$$\rho_{ct} = \frac{1}{\left(\frac{W_f}{\rho_f}\right)+\left(\frac{W_m}{\rho_m}\right)} \quad (2)$$

Where '*W*' and 'ρ' represents the weight fraction and density respectively. The suffix *f, m* and *ct* stand for the fiber, matrix and the composite materials respectively.

3.3.2 Void content

The density and the void content of composite sample have been determined as per ASTM-C 639 and ASTM D-2734-70 standard procedure respectively. The percentage volume fraction of voids (v_v) in the composites was calculated by using equation:

$$v_v = \left(\frac{\rho_{ct}-\rho_{ce}}{\rho_{ct}}\right) X\ 100 \quad (3)$$

Where ρ_{ct} and ρ_{ce} are the theoretical and actual density of composite respectively

Table 3.2: Density of different samples

Fiber %	Theoretical Density	Actual Density	Void Fraction
10	1.023	1.013	0.977
20	0.946	0.938	0.845
30	0.869	0.862	0.718
40	0.792	0.787	0.631

3.3.3 XRD Analysis

The XRD (X-ray Diffractometer X'Pert MPD) analysis of the *Ipomoea carn*ea powder was carried out in Metallurgical and Materials Engineering Department. Phase analysis was studied using room temperature powder X-ray diffraction (Model: PW 3040 Diffractometer, Philips, Holland) will filtered 1.54 Å u Kα radiation. The powder was scanned in a continuous mode with a scanning rate of 3 degrees/min**.**

3.4 TESTING OF MECHANICAL PROPERTIES OF COMPOSITE

3.4.1 Tensile Strength

The tensile test is generally performed on flat specimens cut in the shape of dog-bone. The standard test method as per ASTM D3039-76 was used. The length of the test specimen used was 140 mm and with an average thickness of 4 mm. The tensile test is performed in universal testing machine (UTM) Instron 1195. The tests were performed with a cross head speed of 2mm/min. For each test composite of five samples were tested and average value was taken for analysis. Fig 3.2 (a) and (b) shows the UTM machine and the sample in loading condition. The results of tensile testing are shown in table 3.3.

Fig 3.3: Instiron 1195

3.4.2 Flexural Strength

The three point bend test was carried out in UTM machine in accordance with ASTM D2344-84 to measure the flexural strength of the composites. Specimens of span length 70 mm and 20 mm wide were cut and loaded. The specimens were tested using a load cell of 10kN at 2 mm/min rate of loading. The test was conducted on the same machine used for tensile testing. An average of five tests per sample was performed to find the flexural strength and flexural modulus. The flexural strength for three point bend test was found by using the equation

$$\sigma_{max} = \frac{P_{max}L}{bh^2} \tag{4}$$

Where P_{max} is the maximum load at failure (N), L is the span length, b and h is the width and thickness of the specimen (mm), respectively. The flexural modulus is calculated from the slope of the initial portion of the load-deflection curve which is found out by using equation.

$$\mathrm{E} = \frac{(mL^3)}{4bh^3} \tag{5}$$

Where m is the initial slope of the load deflection curve for each sample. The results obtained are shown in table 3.4.

Fig 3.4: Flexural specimen in loading position

Table 3.3: Tensile properties of *Ipomoea carnea* powder reinforced composite

Fiber volume	Tensile strength(MPa)	Tensile modulus(GPa)
Neat epoxy	13.50	3.941
10	16.7	4.733
20	17.95	5.82
30	23.75	7.205
40	14.52	3.719

Table 3.4: Flexural properties of *Ipomoea carnea* powder reinforced composite

Fiber volume	Flexural strength(MPa)	Flexural modulus(GPa)
Neat epoxy	17.56	2.76
10	23.58	2.352
20	50.92	2.861
30	52.47	4.382
40	35.69	3.289

3.5 RESULTS AND DISCCUSION

The density test results for various specimens which were prepared with *Ipomoea carnea* particles with different volume fraction are plotted in figure 3.5. It is clearly seen that with the increase in fiber content from 10 to 40 wt % there is a decrease in the void fraction. However in all the composites the volume fraction of voids are reasonably small (<1.00%)

The relative proportions of matrix and reinforcing material in a composite decides the density of the composite and density is one of the important factors which determine the properties of the composites. The void content in a composite significantly affect some of the mechanical properties and even the performance of the composite in actual work place. If the void content is higher it results to lower fatigue resistance, greater exposure to water penetration, and weathering [46]. The knowledge of void content is very much essential for estimating the quality of the composite.

The XRD diagram of *Ipomoea carnea* powder is shown in Fig 3.6. From the diffractograms it can be seen that the major crystalline peak in each case occurs at diffraction angle (2θ) of around 21.61°. Another sharp but smaller peak occurs at a diffraction angle of 16.31°.

Figure 3.7 and 3.8 shows the effect of *Ipomoea carnea* particulates on the tensile strength and modulus of the composites. Fiber content (weight %) was varied from 10 to 40 % to investigate its effect on the mechanical properties. From the results it is observed that with increase in fiber content from 10 to 30 % both tensile strength and modulus increases. But thereafter with further increase of fiber content both the properties tend to decrease.

Similar results were obtained during flexural test. Figure 3.9 and 3.10 shows the variation in flexural strength and modulus for different volume fraction of particulate composites. The fig shows that the maximum flexural strength is obtained for the composite prepared with the 30 % volume fraction of particulate filled epoxy composite.

The reason behind this decrease in strength is mainly due to void content and weak interface between fiber and matrix. As the fiber content increases there will be higher fiber to fiber contact which leads to poor interfacial bonding between the fiber and the matrix. Due to this poor interfacial bonding effective load transfer will not take place and leads to failure quickly.

3.6 SEM MICROGRAPH STUDY

To identify the fracture behaviour the morphology of the fractured surface were tested under SEM.Fig.3.11 (a) shows the tensile fractured surface of 30wt% particulate reinforced composite. There is no evidence of micro cracks found in the surface of the composite. The flat fracture surfaces showing river marks are epoxy and at the central part Ipomoea carnea particulates are clearly visible. The 40wt% composite (Fig: 3.11(b)) shows the detachment of particles from the matrix at different place indicating poor fiber matrix adhesion which leads to lowering down of tensile strength. Fig. 3.12 shows the surface of 30 and 40 wt % of fiber under flexural loading. Both the figures shows the removal of particles from the matrix but for the 40% fiber the detachment is more severe. This is the reason which leads to less flexural strength for 40wt% particulate composite.

3.7 CONCLUSIONS

Ipomoea carnea as seen from the present investigation can be used as an effective reinforcement in polymeric composite creating a variety of technological applications beyond its traditional uses. It can also be used as a substitute for wood based composite. The composite prepared have low density compared to synthetic fibers and also to some natural fibers. Therefore it can judiciously be used for producing light weight composite materials. Reinforcement of *Ipomoea carnea* particulate into the epoxy matrix shows improvement in both the tensile and flexural properties compared to pure epoxy.

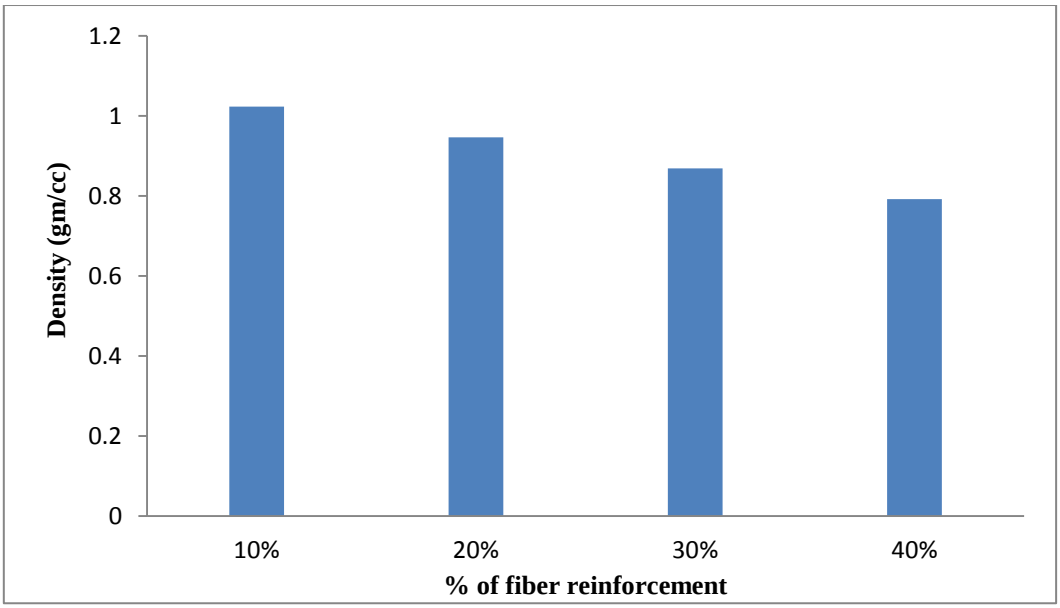

Fig 3.5: Variation of density with fiber content

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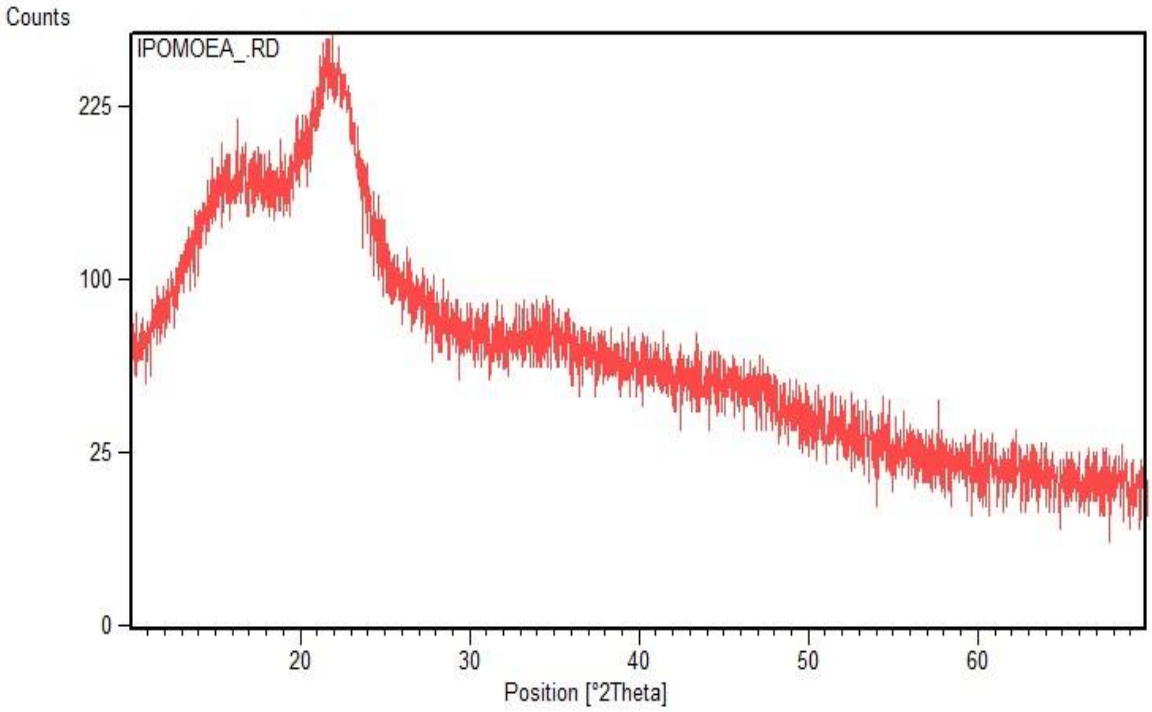

Fig 3.6: X-Ray profile of *Ipomoea carnea* powder

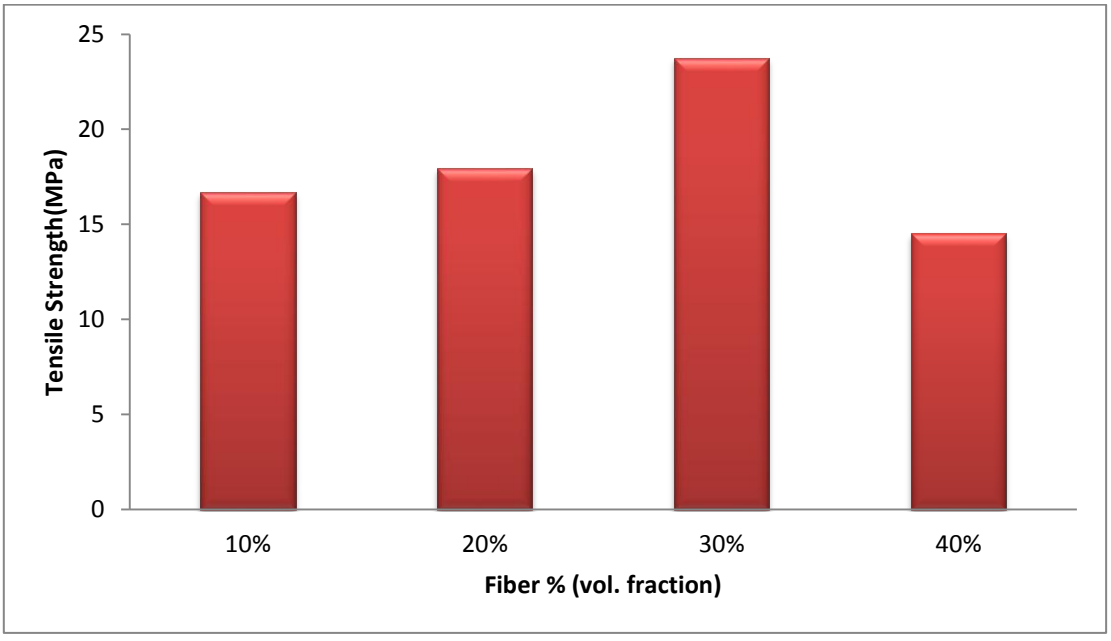

Fig 3.7: Effect of fiber loading on Tensile Strength

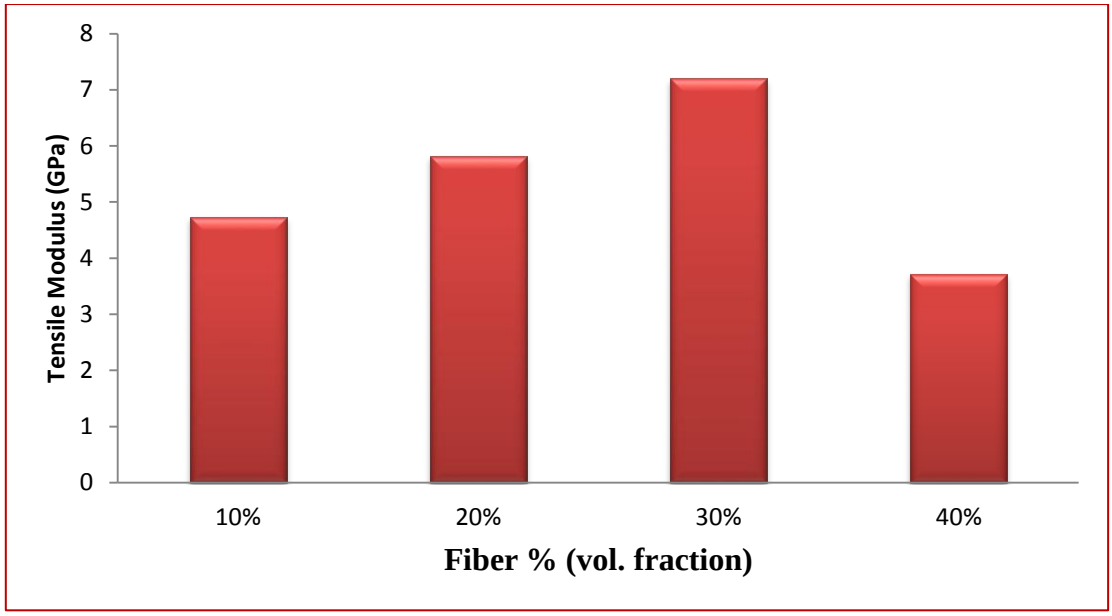

Fig 3.8: Effect of fiber loading on Tensile Modulus

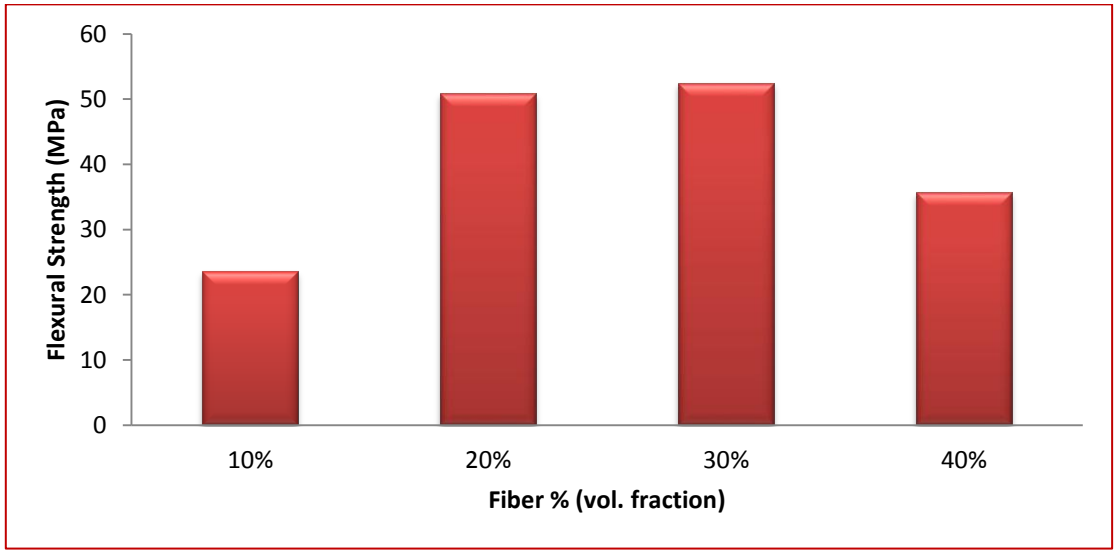

Fig 3.9: Effect of fiber loading on Flexural Strength

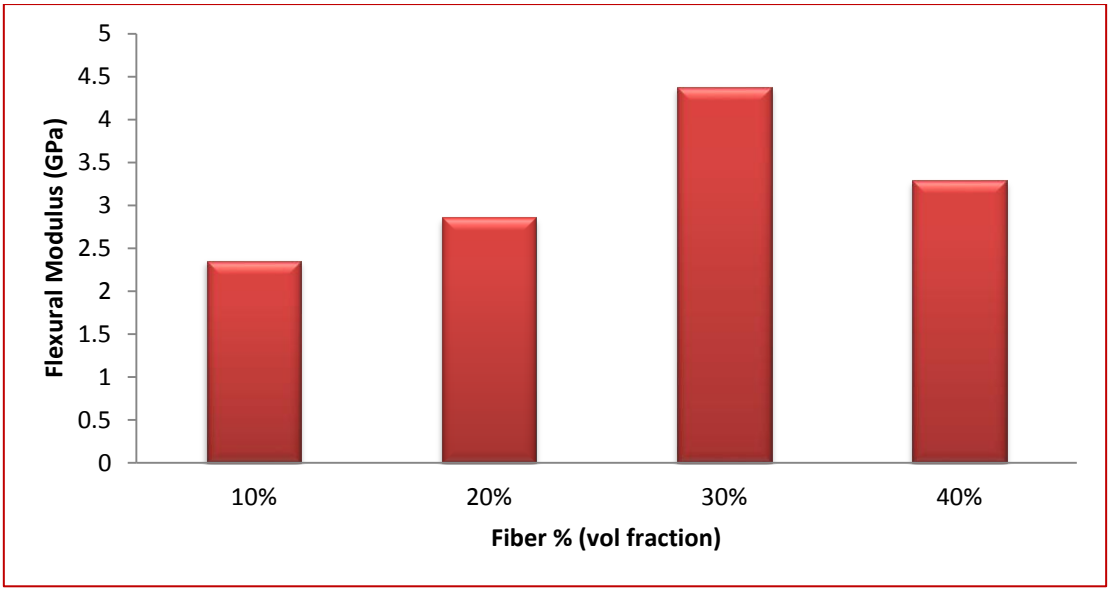

Fig 3.10: Effect of fiber loading on Flexural Modulus

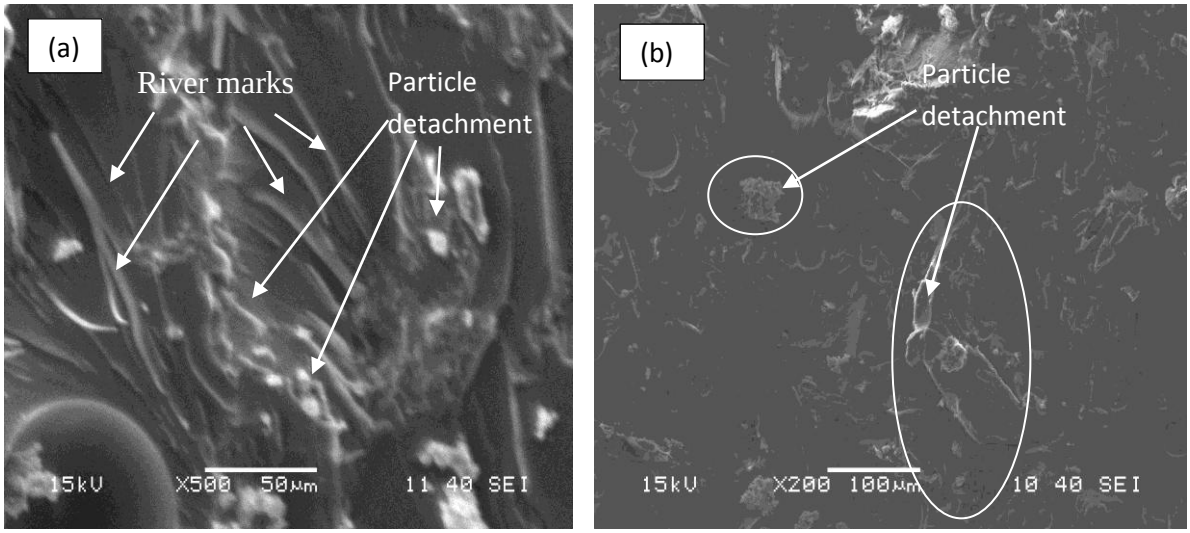

Fig 3.11 (a) SEM micrograph of 30wt% tensile specimen (b) SEM micrograph of 40 wt% tensile specimen

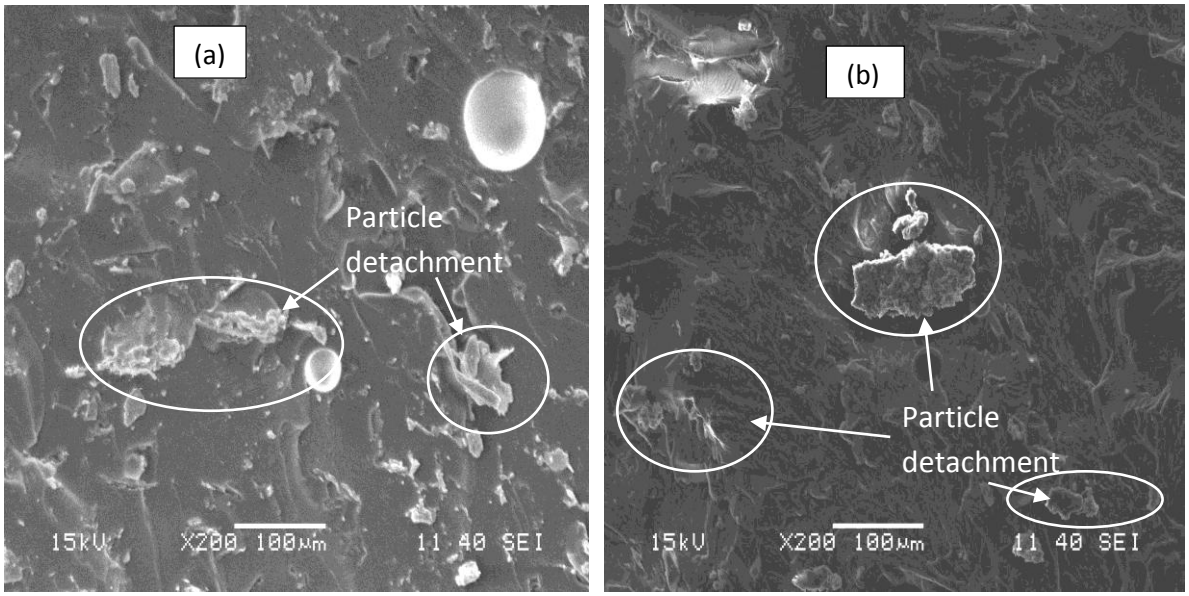

Fig 3.12 (a) SEM micrograph of 30wt% flexural specimen (b) SEM micrograph of 40wt% flexural specimen

Chapter 4

ABRASIVE WEAR OF *IPOMOEA CARNEA* PARTICULATE REINFORCED EPOXY COMPOSITES

CHAPTER 4

4.1 INTRODUCTION

Composites materials are best applicable for aerospace, construction, packaging and automotive industries but it is observed that there are many situations where components made of composites are under tribological loading conditions [47]. 90% of the failure in mechanical parts is due to tribological loading condition [48]. Works on tribological performance evaluation of synthetic fiber based polymer composites has been made for a long time and a good quality work is available on improving friction and wear properties of these composites [47,48] and it is still growing. In the pursuit of visualising the influence of natural fiber reinforced polymer composites in tribological applications, extensive research work has already been published on various types of polymers and fibers. EI-Tayeb [49], Mishra and Acharya [50], Deo and Acharya [51] have reported the tribo potential of sugarcane and *Lantana camara* fiber reinforcement in thermoset polymers for enhancing adhesive wear resistance. Wear may be defined as the progressive loss of material from contacting surfaces in relative motion.

Wear is not an intrinsic material property but characteristics of the engineering system which depend on applied load, speed, temperature, hardness, presence of foreign material and the environmental condition [52]. Widely varied wearing conditions causes wear of materials. It may be due to surface damage or removal of material from one or both the two solid surfaces which are in sliding, rolling or impact motion relative to one another. In most cases wear occurs through surface interactions at asperities. During relative motion, material on contacting surface may be removed from a surface, may result in the transfer to the mating surface, or may break loose as a wear particle. The wear resistance of materials is related to its microstructure may take place during the wear process and hence, it seems that in wear research emphasis is placed on microstructure [53]. Wear of material depends on many variables, so wear research program must be planned systematically. Therefore researchers have normalized some of the data to make them more useful. The wear map proposed by Lim [54] is very much useful in this regard to understand the wear mechanism in different sliding conditions as well as the anticipated rates of wear.

4.2 ABRASIVE WEAR OF POLYMER COMPOSITES

The most dominating wear mechanisms in many fields of industry are abrasion and erosion processes that reduce lifetime of costly machine parts [55] Abrasive wear which constitutes 63% of the total cost of wear is caused when hard asperities of one surface move across another softer surface under load, it penetrates and removes material from the softer surface, leaving grooves and cracks [56]. For components under various tribological loading conditions, it is indispensible to understand the possible wearing mechanism under precise sliding conditions. The main reason behind the failure of such sliding parts is not only breakage but also wear or surface deterioration due to rubbing against other hard surfaces [57]. This lays emphasis on better understanding of sliding wear mechanisms at the worn surfaces in order to design parts with optimum wear and friction characteristics [58, 59].

Literature available on the rate of controlling abrasive wear mechanism demonstrate that it may change abruptly from one another at certain sliding velocities and contact loads, resulting in abrupt increases in wear rates. The conflicting results in the abrasive wear literature arise partly because of the differences in testing conditions, but they also make clear that a deeper understanding of the abrasive wear mechanism is required if an improvement in the wear resistances of the polymer matrix composites is to be achieved. This in turn requires a systematic study of the wear under different loads and velocities. It is generally recognized that abrasive wear is a characteristic of a system and is influenced by many parameters. Laboratory scale investigation if designed properly allows careful control of the tribo system whereby the effects of different variables on wear behaviour of PMCs can be isolated and determined. The data generated through such investigation under controlled conditions may help in correct interpretation of the results.

4.3 EXPERIMENTAL DETAILS

4.3.1 Composite fabrication

The required quantity of particulate (10, 20, 30 and 40 wt. %) were added to resin along with the measured quantity of hardener. A steel mould designed and fabricated at the work-shop was used for preparation of cylindrical (pin) type specimen of length 35mm & diameter of 10 mm [fig 4.1]. The mixture of *Ipomoea carnea* particulate and resin was then poured into the cylindrical cavity present in the mould. The two halves of the mould are then

fixed properly. During fixing some of the resin mixture may squeeze out so a suitable precaution was taken for squeezing out of resin-mix during preparation of composites. After closing of the mould the specimens were allowed to solidify in the mould at the room temperature for 24 hrs. The cured samples were then taken out from the mould and used for abrasive wear test.

4.3.2 Dry Sliding Wear Test

Dry sliding wear test has been carried out under multi-pass condition on a pin-on-disc type wear testing machine (As per ASTM G-99 standard) supplied by Magnum Engineers, Bangalore. Abrasive paper of 400 grade (grit-23 μm) has been pasted on a rotating disc (EN 31 Steel disc) of 120mm diameter using double-sided adhesive tape. The setup is shown in fig 4.2. The specimens under tests were fixed to the sample holder. The holder along with the specimen (Pin) was positioned at a particular track diameter. A track radius of 40mm was selected for this experiment and was kept constant for the entire investigation. For each test new abrasive paper was used and the sample was abraded for a total time of 30mins.

4.3.3 Calculation of Wear

Wear rate was estimated by measuring the weight loss of the specimen after each test. The weight loss was calculated by taking the weight difference of the sample before and after each test. The weight loss:

$$(\Delta w) = (w_a - w_b) \tag{4.1}$$

Where Δw is the weight loss in gm. and w_a and w_b are the weight of the sample after and before the abrasion test in gm. The abrasive wear rate (W) can be calculated by using the following formula:

$$W = \frac{\Delta w}{(\rho \times S_d)} \tag{4.2}$$

Where *'W'* is the wear rate in m^3/m, 'ρ' is the density of the composite, Δw the weight loss in gm and 'S_d' is the sliding distance in m.

The volumetric wear rate Wv (m^3/sec.) of the composite is related to density (ρ) and the abrading time (t), was calculated using the expression,

$$\boldsymbol{W_v = \frac{\Delta w}{\rho \times t}} \tag{4.3}$$

For characterization of the abrasive wear behavior of composite, the specific wear rate is employed. This is defined as the volume loss of the composite per unit sliding distance and per unit applied load. Often the inverse of the specific wear rate can be expressed in terms of volumetric wear rate. The specific wear rate (k_0) can also be calculated by using equation:

$$\boldsymbol{k_0 = \frac{\Delta w}{(\rho \times S_d \times L)}} \tag{4.3}$$

Where 'k_0' is the specific wear rate in m^3/Nm, 'Δw' is the weight loss in grams, 'S_d' is the sliding distance in meter, and 'L' is the applied load in N.

The average value of weight loss, wear rate, specific wear rate and volumetric wear rate for each batch is listed in Table-4.2 to 4.49.

4.4 RESULTS AND DISCUSSION

Based on the experiment and tabulated results, various graphs are plotted and presented in figures 4.4 to 4.18 for different percentage of reinforcement under different test conditions.

Figures 4.4 to 4.7 show the variation of wear rate with sliding distance for different loads (5, 7.5, 10 and 15N) at a sliding velocity of 0.837m/s (200 RPM). It is seen from the plot that with addition of *Ipomoea carnea* particulate the wear rate of epoxy decreases. It has also been observed that the wear rate decreases with increasing sliding distance for all the tested samples. Further it has been observed that, in all cases the range of wear rate is high at the initial stage of sliding distance and achieved a steady state at a distance of about 300 m. In other words, there is less removal of material at longer sliding distances and this could be due to the less penetration of abrasive particle in to the composite sample. Because at initial stage the abrasive paper is fresh and then become smooth due to filling of the space between abrasives by wear debris, which consequently reduce the depth of penetration. It is also observed that the 30 wt% *Ipomoea carnea* particulate reinforced composite shows a

minimum wear rate under all testing conditions. Since the trend for 300 and 400 RPM remains same, it has not been presented here.

The variation of specific wear rate of weight fraction of fiber (10, 20, 30 and 40%) composites with sliding velocity at varying applied loads (5N, 7.5N, 10N and 15N) are presented in figures 4.8 to 4.11. It is seen that as the loading conditions the increases from 5N to 15N the specific wear rate increases linearly with sliding velocity. However it is seen that a constant rate is maintained at higher velocities. It is also noted that the wear rate is very high for neat epoxy than other composite samples. During sliding the normal and tangential loads are transmitted through the contact points by adhesive and ploughing actions, whereas the hard asperities on the counter face or the hard particles between the sliding surfaces plough and micro cut the soft surfaces. Thus, during sliding both adhesive and abrasive wear mechanisms are operative, resulting in powdery wear debris at different sliding velocities. The frictional heat increases with increase in sliding velocity, which reduced the brittleness of both matrix and reinforcing fibers. This behaviour may be attributed to brittleness of the *Ipomoea carnea* particulate.

Figures 4.12 to 4.15 show the variation of specific wear rate of the composite for different fiber weight fractions. It is clear from the plot that, irrespective of sliding velocity the specific wear rate decreases with increase in fiber weight fraction. For sliding velocity of 0.837m/s and 1.675m/s, the decrease of specific wear rate is at a faster rate in comparison to velocity of 1.256m/s. This is more pronounced at higher load i.e. at 7.5N and 10N. However the decrease is marginal for velocity of 1.256m/s from 10 to 30% of fiber weight fraction. But there is a sudden increase in specific wear rate for 40% weight fraction. Thus it can be concluded here that 30% fiber weight fraction can be taken as optimum with a velocity of 1.256m/s for the composite under study.

Figures 4.16 to 4.18 show the variation of volumetric wear rate with normal loads for different weight fraction of fiber composites at different velocities. It is observed from the plots that volumetric wear rate increases with the increase of normal loads. Wear rate was relatively low at normal load (5N) because of lower penetration and less number of abrasive particles in action with the rubbing surfaces. Abrasion wear was greatly increased at higher load because most of the abrasive particles come into action and creates more grooves. The grooving action results more material removal and can be termed as ploughing. This can also be attributed to the fact that at higher loads the frictional thrust increases, which result in

increased debonding and fracture. A similar effect of normal load on volumetric wear rate has been observed by Cirino *et al* [60] in the case of carbon epoxy composite and Verma *et al* [61] for GRP composite. Thus it can be said that *Ipomoea carnea* particulate addition is very effective in improving the tribological properties of epoxy specially its wear resistance.

4.5 WORN SURFACE MORPHOLOGY

The surface topology of 30 wt % fiber as shown in fig 4.19(a) is not smooth. Matrix cracking is clearly visible however there is no sign of detachment of particles from the matrix which probably increase the wear resistance of the composite. Fig 4.19(b) shows the same view at higher magnification. Due to higher loads particulates are elongated along the rolling direction but are still intact with the matrix.

4.6 CONCLUSIONS

Based on experimental results of abrasive wear of *Ipomoea carnea* particulate epoxy composite tested under different normal loads, sliding velocity and sliding distances, the following conclusions have been drawn:

1. The incorporation of *Ipomoea carnea* into epoxy can significantly reduce abrasive wear loss. The optimum wear resistance property was obtained at a fibre content of 30 per cent weight fraction. However, excessive addition of fiber (40%) results in drawing out of the fiber from the matrix resin during the test due to poor interfacial adhesion.
2. Abrasive wear is very sensitive to normal load compared to sliding velocity and increases marginally with increasing sliding velocity.
3. With increasing sliding distance, wear rate gradually decreases and attains an almost steady state in multi-pass condition.
4. The specific wear rate of the composite decreases with an increase in sliding distance because the space between the abrasive is filled by the debris, which reduces the depth of penetration of abrasive particles into the composite sample.

Table 4.1: Test Parameter for Dry Sliding wear Test

Test Parameters	Units	Values
Weight fraction of Fiber	%	10, 20, 30 and 40
Load (L)	N	5,7.5,10 and 15
Sliding Velocity	m/s	0.837, 1.256 and 1.675
Track radius (r)	mm	40
Temperature	°C	25

Table 4.2

Weight fraction -10% **Load-5N** **Velocity-0.8377m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.375	3.265	0.11	300	0.251	0.432072	0.086414	0.361961
3.375	3.2	0.175	600	0.502	0.343694	0.068739	0.287924
3.375	3.168	0.207	900	0.753	0.271027	0.054205	0.227048
3.375	3.155	0.220	1200	1.005	0.216036	0.043207	0.180981
3.375	3.142	0.233	1500	1.256	0.183041	0.036608	0.15334
3.375	3.13	0.245	1800	1.507	0.16039	0.032078	0.134364

Table 4.3

Weight fraction -10% **Load-7.5N** **Velocity-0.8377m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.512	3.284	0.228	300	0.251	0.895568	0.119409	0.750246
3.512	3.201	0.311	600	0.502	0.610793	0.081439	0.511681
3.512	3.143	0.369	900	0.753	0.483135	0.064418	0.404738
3.512	3.131	0.381	1200	1.005	0.374135	0.049885	0.313425
3.512	3.105	0.407	1500	1.256	0.319733	0.042631	0.267851
3.512	3.053	0.459	1800	1.507	0.300486	0.040065	0.251727

Table 4.4

Weight fraction -10% Load-10N Velocity-0.8377m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.508	3.223	0.285	300	0.251	1.119459	0.111946	0.937808
3.508	3.115	0.393	600	0.502	0.771838	0.077184	0.646594
3.508	3.029	0.479	900	0.753	0.627159	0.062716	0.525392
3.508	2.955	0.553	1200	1.005	0.543036	0.054304	0.454919
3.508	2.907	0.601	1500	1.256	0.472137	0.047214	0.395525
3.508	2.392	1.116	1800	1.507	0.730595	0.073059	0.612043

Table 4.5

Weight fraction -10% Load-15N Velocity-0.8377m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.861	2.775	0.086	300	0.251	0.337802	0.02252	0.282988
2.861	2.746	0.115	600	0.502	0.225856	0.015057	0.189207
2.861	2.742	0.119	900	0.753	0.155808	0.010387	0.130525
2.861	2.734	0.127	1200	1.005	0.124712	0.008314	0.104475
2.861	2.699	0.162	1500	1.256	0.127265	0.008484	0.106614
2.861	2.679	0.182	1800	1.507	0.119147	0.007943	0.099813

Table 4.6

Weight fraction -20% **Load-5N** **Velocity-0.8377m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.547	3.445	0.012	300	0.251	0.432683	0.086537	0.362473
3.547	3.349	0.188	600	0.502	0.398747	0.079749	0.334044
3.547	3.312	0.235	900	0.753	0.33229	0.066458	0.27837
3.547	3.279	0.268	1200	1.005	0.284214	0.056843	0.238095
3.547	3.242	0.305	1500	1.256	0.258762	0.051752	0.216773
3.547	3.239	0.308	1800	1.507	0.217756	0.043551	0.182421

Table 4.7

Weight fraction -20% **Load-7.5N** **Velocity-0.8377m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.725	2.522	0.203	300	0.251	0.861125	0.114817	0.721393
2.725	2.413	0.312	600	0.502	0.661751	0.088233	0.554371
2.725	2.323	0.402	900	0.753	0.568427	0.07579	0.47619
2.725	2.236	0.489	1200	1.005	0.518584	0.069145	0.434435
2.725	2.173	0.552	1500	1.256	0.468316	0.062442	0.392324
2.725	2.115	0.61	1800	1.507	0.431269	0.057503	0.361289

Table 4.8

Weight fraction -20% **Load-10N** **Velocity-0.8377m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.634	3.559	0.075	300	0.251	0.31815	0.031815	0.266524
3.634	3.500	0.134	600	0.502	0.284214	0.028421	0.238095
3.634	3.479	0.155	900	0.753	0.21917	0.021917	0.183606
3.634	3.441	0.193	1200	1.005	0.204676	0.020468	0.171464
3.634	3.41	0.224	1500	1.256	0.190041	0.019004	0.159204
3.634	3.374	0.260	1800	1.507	0.18382	0.018382	0.153992

Table 4.9

Weight fraction -20% **Load-15N** **Velocity-0.8377m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.908	2.72	0.188	300	0.251	0.797495	0.053166	0.668088
2.908	2.652	0.256	600	0.502	0.542975	0.036198	0.454868
2.908	2.629	0.279	900	0.753	0.394505	0.0263	0.33049
2.908	2.602	0.306	1200	1.005	0.324513	0.021634	0.271855
2.908	2.580	0.328	1500	1.256	0.278275	0.018552	0.23312
2.908	2.561	0.347	1800	1.507	0.245329	0.016355	0.20552

Table 4.10

Weight fraction -30% Load-5N Velocity-0.8377m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.657	2.543	0.114	300	0.251	0.526224	0.105245	0.440835
2.657	2.509	0.148	600	0.502	0.341584	0.068317	0.286156
2.657	2.481	0.176	900	0.753	0.270805	0.054161	0.226863
2.657	2.448	0.209	1200	1.005	0.241186	0.048237	0.202049
2.657	2.427	0.230	1500	1.256	0.212336	0.042467	0.177881
2.657	2.409	0.248	1800	1.507	0.190795	0.038159	0.159835

Table 4.11

Weight fraction -30% Load-7.5N Velocity-0.8377m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.637	2.468	0.169	300	0.251	0.780104	0.104014	0.653519
2.637	2.398	0.239	600	0.502	0.551612	0.073548	0.462103
2.637	2.357	0.280	900	0.753	0.430827	0.057444	0.360918
2.637	2.326	0.311	1200	1.005	0.358894	0.047853	0.300657
2.637	2.300	0.337	1500	1.256	0.311118	0.041482	0.260634
2.637	2.277	0.360	1800	1.507	0.27696	0.036928	0.232018

Table 4.12

Weight fraction -30% Load-10N Velocity-0.8377m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.591	2.437	0.154	300	0.251	0.710864	0.071086	0.595514
2.591	2.404	0.187	600	0.502	0.431596	0.04316	0.361562
2.591	2.369	0.222	900	0.753	0.341584	0.034158	0.286156
2.591	2.352	0.239	1200	1.005	0.275806	0.027581	0.231052
2.591	2.340	0.251	1500	1.256	0.231723	0.023172	0.194122
2.591	2.325	0.266	1800	1.507	0.204643	0.020464	0.171436

Table 4.13

Weight fraction -30% Load-15N Velocity-0.8377m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.613	3.451	0.162	300	0.251	0.747792	0.049853	0.62645
3.613	3.354	0.259	600	0.502	0.597772	0.039851	0.500773
3.613	3.274	0.339	900	0.753	0.521608	0.034774	0.436968
3.613	3.200	0.413	1200	1.005	0.476602	0.031773	0.399265
3.613	3.145	0.468	1500	1.256	0.432057	0.028804	0.361949
3.613	3.117	0.496	1800	1.507	0.381589	0.025439	0.31967

Table 4.14

Weight fraction -40% **Load-5N** **Velocity-0.8377m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.502	2.407	0.095	300	0.251	0.48031	0.096062	0.402372
2.502	2.374	0.128	600	0.502	0.323577	0.064715	0.271071
2.502	2.337	0.165	900	0.753	0.278074	0.055615	0.232952
2.502	2.301	0.201	1200	1.005	0.254059	0.050812	0.212833
2.502	2.266	0.236	1500	1.256	0.238638	0.047728	0.199915
2.502	2.228	0.274	1800	1.507	0.230886	0.046177	0.193421

Table 4.15

Weight fraction -40% **Load-7.5N** **Velocity-0.8377m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.652	2.516	0.136	300	0.251	0.687602	0.09168	0.576027
2.652	2.382	0.27	600	0.502	0.682546	0.091006	0.571791
2.652	2.306	0.346	900	0.753	0.583113	0.077748	0.488493
2.652	2.262	0.39	1200	1.005	0.49295	0.065727	0.41296
2.652	2.209	0.443	1500	1.256	0.447952	0.059727	0.375265
2.652	2.177	0.475	1800	1.507	0.400259	0.053368	0.33531

Table 4.16

Weight fraction -40% Load-10N Velocity-0.8377m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.625	2.548	0.077	300	0.251	0.389304	0.03893	0.326133
2.625	2.504	0.121	600	0.502	0.305882	0.030588	0.256247
2.625	2.466	0.159	900	0.753	0.267963	0.026796	0.224481
2.625	2.44	0.185	1200	1.005	0.233835	0.023384	0.195891
2.625	2.414	0.211	1500	1.256	0.213359	0.021336	0.178738
2.625	2.396	0.229	1800	1.507	0.192967	0.019297	0.161655

Table 4.17

Weight fraction -40% Load-15N Velocity-0.8377m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.608	2.487	0.121	300	0.251	0.611764	0.040784	0.512495
2.608	2.427	0.181	600	0.502	0.457559	0.030504	0.383312
2.608	2.384	0.224	900	0.753	0.377507	0.025167	0.31625
2.608	2.346	0.262	1200	1.005	0.331161	0.022077	0.277425
2.608	2.31	0.298	1500	1.256	0.301331	0.020089	0.252435
2.608	2.273	0.335	1800	1.507	0.282288	0.018819	0.236482

Table 4.18

Weight fraction -10% Load-5N Velocity-1.256m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.945	2.746	0.199	300	0.37698	0.521105	0.104221	0.654821
2.945	2.632	0.313	600	0.75396	0.409814	0.081963	0.514972
2.945	2.53	0.415	900	1.13094	0.362242	0.072448	0.455194
2.945	2.444	0.501	1200	1.50792	0.327982	0.065596	0.412142
2.945	2.406	0.539	1500	1.8849	0.282287	0.056457	0.354722
2.945	2.374	0.571	1800	2.26188	0.249205	0.049841	0.313151

Table 4.19

Weight fraction -10% Load-7.5N Velocity-1.256m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.169	2.968	0.201	300	0.37698	0.526342	0.070179	0.661402
3.169	2.884	0.285	600	0.75396	0.373153	0.049754	0.468904
3.169	2.78	0.389	900	1.13094	0.339548	0.045273	0.426675
3.169	2.725	0.444	1200	1.50792	0.290667	0.038756	0.365252
3.169	2.676	0.493	1500	1.8849	0.258196	0.034426	0.324449
3.169	2.663	0.506	1800	2.26188	0.220837	0.029445	0.277504

Table 4.20

Weight fraction -10% **Load-10N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.518	3.327	0.191	300	0.37698	0.500156	0.050016	0.628496
3.518	3.3	0.218	600	0.75396	0.285429	0.028543	0.358671
3.518	3.275	0.243	900	1.13094	0.212108	0.021211	0.266535
3.518	3.261	0.257	1200	1.50792	0.168246	0.016825	0.211418
3.518	3.249	0.269	1500	1.8849	0.140882	0.014088	0.177032
3.518	3.239	0.279	1800	2.26188	0.121766	0.012177	0.153011

Table 4.21

Weight fraction -10% **Load-15N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.807	2.716	0.091	300	0.37698	0.238294	0.015886	0.299441
2.807	2.689	0.118	600	0.75396	0.154498	0.0103	0.194143
2.807	2.671	0.136	900	1.13094	0.118711	0.007914	0.149172
2.807	2.652	0.155	1200	1.50792	0.101471	0.006765	0.127509
2.807	2.631	0.176	1500	1.8849	0.092175	0.006145	0.115828
2.807	2.613	0.194	1800	2.26188	0.084669	0.005645	0.106395

Table 4.22

Weight fraction -20% **Load-5N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.674	2.368	0.306	300	0.37698	0.865367	0.173073	1.08742
2.674	2.26	0.414	600	0.75396	0.585395	0.117079	0.735608
2.674	2.157	0.517	900	1.13094	0.487358	0.097472	0.612414
2.674	2.08	0.594	1200	1.50792	0.419957	0.083991	0.527719
2.674	2.007	0.667	1500	1.8849	0.377255	0.075451	0.474058
2.674	1.938	0.736	1800	2.26188	0.346901	0.06938	0.435916

Table 4.23

Weight fraction -20% **Load-7.5N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.872	2.188	0.684	300	0.37698	1.93435	0.257913	2.430704
2.872	1.9	0.972	600	0.75396	1.374406	0.183254	1.727079
2.872	1.754	1.118	900	1.13094	1.0539	0.14052	1.324331
2.872	1.67	1.202	1200	1.50792	0.849813	0.113308	1.067875
2.872	1.603	1.269	1500	1.8849	0.717745	0.095699	0.901919
2.872	1.578	1.294	1800	2.26188	0.609905	0.081321	0.766406

Table 4.24

Weight fraction -20% **Load-10N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.547	2.173	0.374	300	0.37698	1.057671	0.105767	1.329069
2.547	1.925	0.622	600	0.75396	2.010705	0.201071	2.526652
2.547	1.853	0.694	900	1.13094	0.65421	0.065421	0.82208
2.547	1.762	0.785	1200	1.50792	0.554994	0.055499	0.697406
2.547	1.736	0.811	1500	1.8849	0.458701	0.04587	0.576404
2.547	1.692	0.855	1800	2.26188	0.402989	0.040299	0.506397

Table 4.25

Weight fraction -20% **Load-15N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.483	3.072	0.411	300	0.37698	1.162307	0.077487	1.460554
3.483	2.856	0.627	600	0.75396	0.886577	0.059105	1.114072
3.483	2.639	0.844	900	1.13094	0.79561	0.053041	0.999763
3.483	2.365	1.118	1200	1.50792	0.790425	0.052695	0.993248
3.483	2.221	1.262	1500	1.8849	0.713786	0.047586	0.896944
3.483	1.992	1.491	1800	2.26188	0.702757	0.04685	0.883085

Table 4.26

Weight fraction -30% Load-5N Velocity-1.256m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.981	2.724	0.257	300	0.37698	0.790874	0.158175	0.993813
2.981	2.487	0.494	600	0.75396	0.760101	0.15202	0.955143
2.981	2.28	0.701	900	1.13094	0.71907	0.143814	0.903583
2.981	2.107	0.874	1200	1.50792	0.672397	0.134479	0.844934
2.981	1.957	1.024	1500	1.8849	0.630238	0.126048	0.791957
2.981	1.812	1.169	1800	2.26188	0.599567	0.119913	0.753416

Table 4.27

Weight fraction -30% Load-7.5N Velocity-1.256m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.176	2.772	0.404	300	0.37698	1.243242	0.165766	1.562258
3.176	2.52	0.656	600	0.75396	1.009365	0.134582	1.268368
3.176	2.358	0.818	900	1.13094	0.839086	0.111878	1.054395
3.176	2.184	0.992	1200	1.50792	0.763178	0.101757	0.95901
3.176	2.03	1.146	1500	1.8849	0.705325	0.094043	0.886311
3.176	1.9	1.276	1800	2.26188	0.654446	0.087259	0.822377

Table 4.28

Weight fraction -30% **Load-10N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.057	2.601	0.456	300	0.37698	1.403264	0.140326	1.763341
3.057	2.168	0.889	600	0.75396	1.367874	0.136787	1.718871
3.057	1.936	1.121	900	1.13094	1.149897	0.11499	1.44496
3.057	1.77	1.287	1200	1.50792	0.990132	0.099013	1.2442
3.057	1.659	1.398	1500	1.8849	0.860422	0.086042	1.081206
3.057	1.63	1.427	1800	2.26188	0.731892	0.073189	0.919696

Table 4.29

Weight fraction -30% **Load-15N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.867	2.43	0.437	300	0.37698	1.344794	0.089653	1.689869
2.867	1.999	0.868	600	0.75396	1.335562	0.089037	1.678268
2.867	1.78	1.087	900	1.13094	1.11502	0.074335	1.401134
2.867	1.547	1.32	1200	1.50792	1.01552	0.067701	1.276102
2.867	2.025	0.643	1500	1.8849	0.395745	0.026383	0.497293
2.867	1.601	1.067	1800	2.26188	0.547252	0.036483	0.687677

Table 4.30

Weight fraction -40% **Load-5N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.333	2.036	0.297	300	0.37698	1.001068	0.200214	1.257942
2.333	1.824	0.509	600	0.75396	0.857817	0.171563	1.077933
2.333	1.652	0.681	900	1.13094	0.765126	0.153025	0.961457
2.333	1.54	0.793	1200	1.50792	0.668221	0.133644	0.839687
2.333	1.407	0.926	1500	1.8849	0.624235	0.124847	0.784413
2.333	1.404	0.929	1800	2.26188	0.521881	0.104376	0.655796

Table 4.31

Weight fraction -40% **Load-7.5N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.791	2.317	0.474	300	0.37698	1.597663	0.213022	2.007624
2.791	2.113	0.678	600	0.75396	1.142633	0.152351	1.435832
2.791	1.993	0.798	900	1.13094	0.896579	0.119544	1.126641
2.791	1.777	1.014	1200	1.50792	0.854447	0.113926	1.073698
2.791	1.659	1.132	1500	1.8849	0.763103	0.101747	0.958916
2.791	1.640	1.151	1800	2.26188	0.646593	0.086212	0.812509

Table 4.32

Weight fraction -40% **Load-10N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.880	2.230	0.650	300	0.37698	2.190889	0.219089	2.753071
2.880	1.960	0.920	600	0.75396	1.550475	0.155048	1.948327
2.880	1.746	1.134	900	1.13094	1.274086	0.127409	1.601017
2.880	1.530	1.350	1200	1.50792	1.137577	0.113758	1.429479
2.880	1.509	1.371	1500	1.8849	0.924218	0.092422	1.161372
2.880	1.47	1.410	1800	2.26188	0.792091	0.079209	0.995341

Table 4.33

Weight fraction -40% **Load-15N** **Velocity-1.256m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.044	2.51	0.534	300	0.37698	1.799899	0.119993	2.261753
3.044	2.222	0.822	600	0.75396	1.385316	0.092354	1.740788
3.044	2.015	1.029	900	1.13094	1.156115	0.077074	1.452774
3.044	1.818	1.226	1200	1.50792	1.033088	0.068873	1.298179
3.044	1.699	1.345	1500	1.8849	0.906691	0.060446	1.139348
3.044	1.651	1.393	1800	2.26188	0.782541	0.052169	0.98334

Table 4.34

Weight fraction -10% **Load-5N** **Velocity-1.675m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.566	2.198	0.368	300	0.50264	0.722739	0.144548	1.21092
2.566	1.853	0.713	600	1.00528	0.700153	0.140031	1.173079
2.566	1.802	0.764	900	1.50792	0.500156	0.100031	0.837992
2.566	1.671	0.895	1200	2.01056	0.439437	0.087887	0.736259
2.566	1.667	0.899	1500	2.5132	0.353121	0.070624	0.59164
2.566	1.66	0.906	1800	3.01584	0.296559	0.059312	0.496872

Table 4.35

Weight fraction -10% **Load-7.5N** **Velocity-1.675m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.108	2.511	0.597	300	0.50264	1.172486	0.156332	1.964454
3.108	2.173	0.935	600	1.00528	0.918153	0.12242	1.538329
3.108	2.057	1.051	900	1.50792	0.688042	0.091739	1.152787
3.108	1.931	1.177	1200	2.01056	0.577896	0.077053	0.968242
3.108	1.681	1.427	1500	2.5132	0.560515	0.074735	0.939121
3.108	1.576	1.532	1800	3.01584	0.501465	0.066862	0.840185

Table 4.36

Weight fraction -10% Load-10N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.899	2.539	0.360	300	0.50264	0.707027	0.070703	1.184595
2.899	2.266	0.633	600	1.00528	0.621595	0.062159	1.041457
2.899	2.100	0.799	900	1.50792	0.523069	0.052307	0.876381
2.899	1.869	1.030	1200	2.01056	0.505721	0.050572	0.847315
2.899	1.756	1.143	1500	2.5132	0.448962	0.044896	0.752218
2.899	1.623	1.276	1800	3.01584	0.41767	0.041767	0.699789

Table 4.37

Weight fraction -10% Load-15N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.975	2.526	0.449	300	0.50264	0.88182	0.058788	1.477454
2.975	2.31	0.665	600	1.00528	0.653018	0.043535	1.094106
2.975	2.174	0.801	900	1.50792	0.524378	0.034959	0.878575
2.975	2.047	0.928	1200	2.01056	0.45564	0.030376	0.763406
2.975	1.902	1.073	1500	2.5132	0.421467	0.028098	0.706151
2.975	1.688	1.287	1800	3.01584	0.42127	0.028085	0.705821

Table 4.38

Weight fraction -20% Load-5N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.009	2.667	0.342	300	0.50264	0.725381	0.145076	1.215347
3.009	2.489	0.520	600	1.00528	0.551459	0.110292	0.923948
3.009	2.337	0.672	900	1.50792	0.475103	0.095021	0.796017
3.009	2.185	0.824	1200	2.01056	0.436925	0.087385	0.732051
3.009	2.055	0.954	1500	2.5132	0.404686	0.080937	0.678036
3.009	1.934	1.075	1800	3.01584	0.380012	0.076002	0.636695

Table 4.39

Weight fraction -20% Load-7.5N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.065	2.566	0.499	300	0.50264	1.058378	0.141117	1.773269
3.065	2.327	0.738	600	1.00528	0.782648	0.104353	1.311295
3.065	2.124	0.941	900	1.50792	0.665286	0.088705	1.11466
3.065	2.053	1.012	1200	2.01056	0.536612	0.071548	0.899072
3.065	1.885	1.180	1500	2.5132	0.500555	0.066741	0.83866
3.065	1.703	1.362	1800	3.01584	0.481466	0.064196	0.806678

Table 4.40

Weight fraction -20% Load-10N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.547	2.173	0.374	300	0.50264	0.793253	0.079325	1.329064
2.547	1.125	1.422	600	1.00528	1.508029	0.150803	2.526642
2.547	1.853	0.694	900	1.50792	0.490657	0.049066	0.822077
2.547	1.762	0.785	1200	2.01056	0.416246	0.041625	0.697403
2.547	1.736	0.811	1500	2.5132	0.344026	0.034403	0.576401
2.547	1.692	0.855	1800	3.01584	0.302242	0.030224	0.506395

Table 4.41

Weight fraction -20% Load-15N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.857	2.395	0.462	300	0.50264	0.979901	0.065327	1.641785
2.857	2.168	0.689	600	1.00528	0.730684	0.048712	1.224231
2.857	1.986	0.871	900	1.50792	0.615796	0.041053	1.031742
2.857	1.911	0.946	1200	2.01056	0.501616	0.033441	0.840437
2.857	1.712	1.145	1500	2.5132	0.485708	0.032381	0.813785
2.857	1.63	1.227	1800	3.01584	0.433744	0.028916	0.726721

Table 4.42

Weight fraction -30% **Load-5N** **Velocity-1.675m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.790	2.534	0.256	300	0.50264	0.590848	0.11817	0.989942
2.790	2.305	0.485	600	1.00528	0.55969	0.111938	0.937738
2.790	2.198	0.592	900	1.50792	0.455445	0.091089	0.76308
2.790	2.008	0.782	1200	2.01056	0.451214	0.090243	0.755991
2.790	1.871	0.919	1500	2.5132	0.42421	0.084842	0.710747
2.790	1.663	1.127	1800	3.01584	0.433519	0.086704	0.726344

Table 4.43

Weight fraction -30% **Load-7.5N** **Velocity-1.675m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.009	2.543	0.466	300	0.50264	1.075528	0.143404	1.802004
3.009	2.32	0.689	600	1.00528	0.795106	0.106014	1.332168
3.009	2.079	0.930	900	1.50792	0.71548	0.095397	1.198758
3.009	1.905	1.104	1200	2.01056	0.637008	0.084934	1.067281
3.009	1.751	1.258	1500	2.5132	0.580693	0.077426	0.972927
3.009	1.646	1.363	1800	3.01584	0.524301	0.069907	0.878445

Table 4.44

Weight fraction -30% Load-10N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.460	2.684	0.776	300	0.50264	1.791008	0.179101	3.000761
3.460	2.371	1.089	600	1.00528	1.256706	0.125671	2.10556
3.460	2.103	1.357	900	1.50792	1.043985	0.104399	1.749155
3.460	2.015	1.445	1200	2.01056	0.833765	0.083376	1.39694
3.460	1.936	1.524	1500	2.5132	0.703478	0.070348	1.17865
3.460	1.622	1.838	1800	3.01584	0.707017	0.070702	1.184579

Table 4.45

Weight fraction -30% Load-15N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.867	2.43	0.437	300	0.50264	1.008596	0.06724	1.689862
2.867	1.999	0.868	600	1.00528	1.001672	0.066778	1.678261
2.867	1.78	1.087	900	1.50792	0.836265	0.055751	1.401129
2.867	1.547	1.32	1200	2.01056	0.76164	0.050776	1.276097
2.668	2.025	0.643	1500	2.5132	0.296809	0.019787	0.497291
2.668	1.601	1.067	1800	3.01584	0.410439	0.027363	0.687675

Table 4.46

Weight fraction -40% **Load-5N** **Velocity-1.675m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.061	2.976	0.085	300	0.50264	0.214876	0.042975	0.360016
3.061	2.521	0.54	600	1.00528	0.682546	0.136509	1.143579
3.061	2.211	0.85	900	1.50792	0.716252	0.14325	1.200052
3.061	1.923	1.138	1200	2.01056	0.719201	0.14384	1.204993
3.061	1.797	1.264	1500	2.5132	0.639065	0.127813	1.070728
3.061	1.638	1.423	1800	3.01584	0.599545	0.119909	1.004514

Table 4.47

Weight fraction -40% **Load-7.5N** **Velocity-1.675m/s**

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	$S_d X10^3$ (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.791	2.317	0.474	300	0.50264	1.198248	0.159766	2.007616
2.791	2.113	0.678	600	1.00528	0.856975	0.114263	1.435827
2.791	1.993	0.798	900	1.50792	0.672434	0.089658	1.126637
2.791	1.777	1.014	1200	2.01056	0.640835	0.085445	1.073693
2.791	1.659	1.132	1500	2.5132	0.572328	0.07631	0.958912
2.791	1.64	1.151	1800	3.01584	0.484945	0.064659	0.812506

Table 4.48

Weight fraction -40% Load-10N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
2.880	2.23	0.65	300	0.50264	1.643167	0.164317	2.75306
2.880	1.96	0.92	600	1.00528	1.162856	0.116286	1.948319
2.880	1.746	1.134	900	1.50792	0.955565	0.095556	1.60101
2.880	1.53	1.35	1200	2.01056	0.853183	0.085318	1.429473
2.880	1.509	1.371	1500	2.5132	0.693163	0.069316	1.161368
2.880	1.47	1.41	1800	3.01584	0.594068	0.059407	0.995337

Table 4.49

Weight fraction -40% Load-15N Velocity-1.675m/s

m_1 (gm.)	m_2 (gm.)	Δm (gm.)	t (sec)	S_dX10^3 (m)	$WrX10^{-6}$ (m^3/m)	$WsX10^{-11}$ ($m^3/N.m$)	$WvX10^{-9}$ (m^3/s)
3.044	2.51	0.534	300	0.50264	1.349924	0.089995	2.261744
3.044	2.222	0.822	600	1.00528	1.038987	0.069266	1.740781
3.044	2.015	1.029	900	1.50792	0.867086	0.057806	1.452768
3.044	1.818	1.226	1200	2.01056	0.774816	0.051654	1.298174
3.044	1.699	1.345	1500	2.5132	0.680018	0.045335	1.139343
3.044	1.651	1.393	1800	3.01584	0.586905	0.039127	0.983336

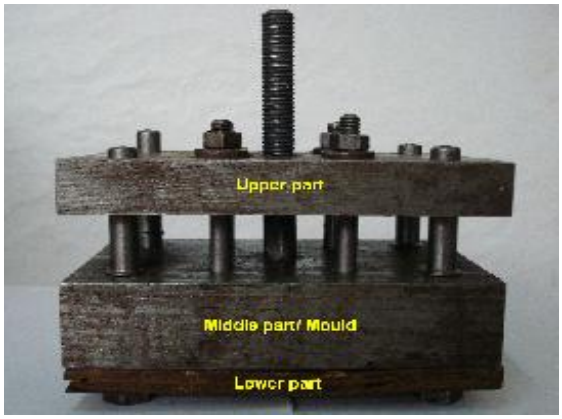

Fig 4.1: Mould for sample preparation

Fig 4.2: Pin-on-disc type wear testing machine

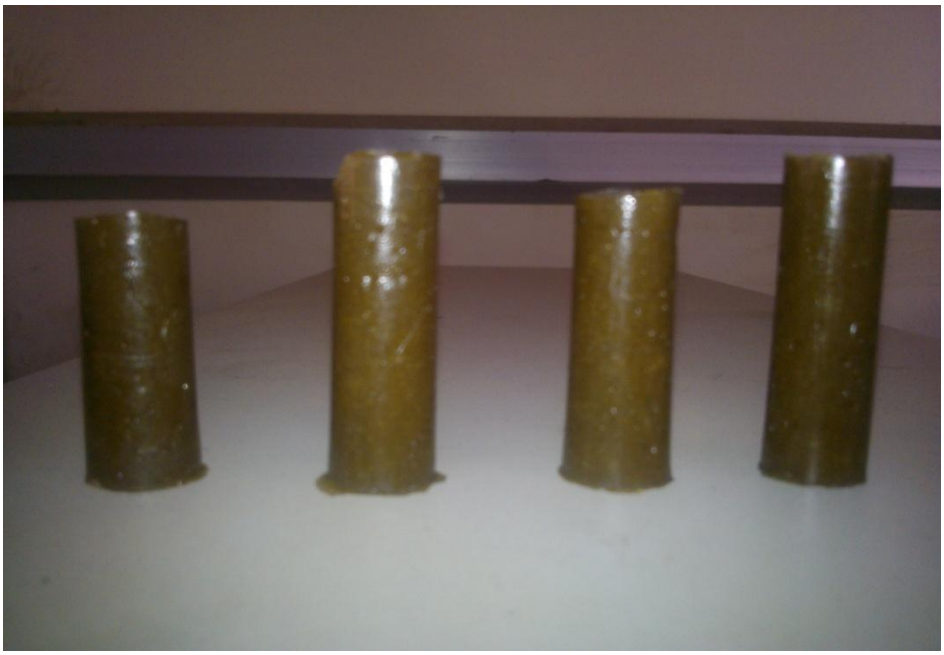

Fig 4.3: Fabricated Composite Pins

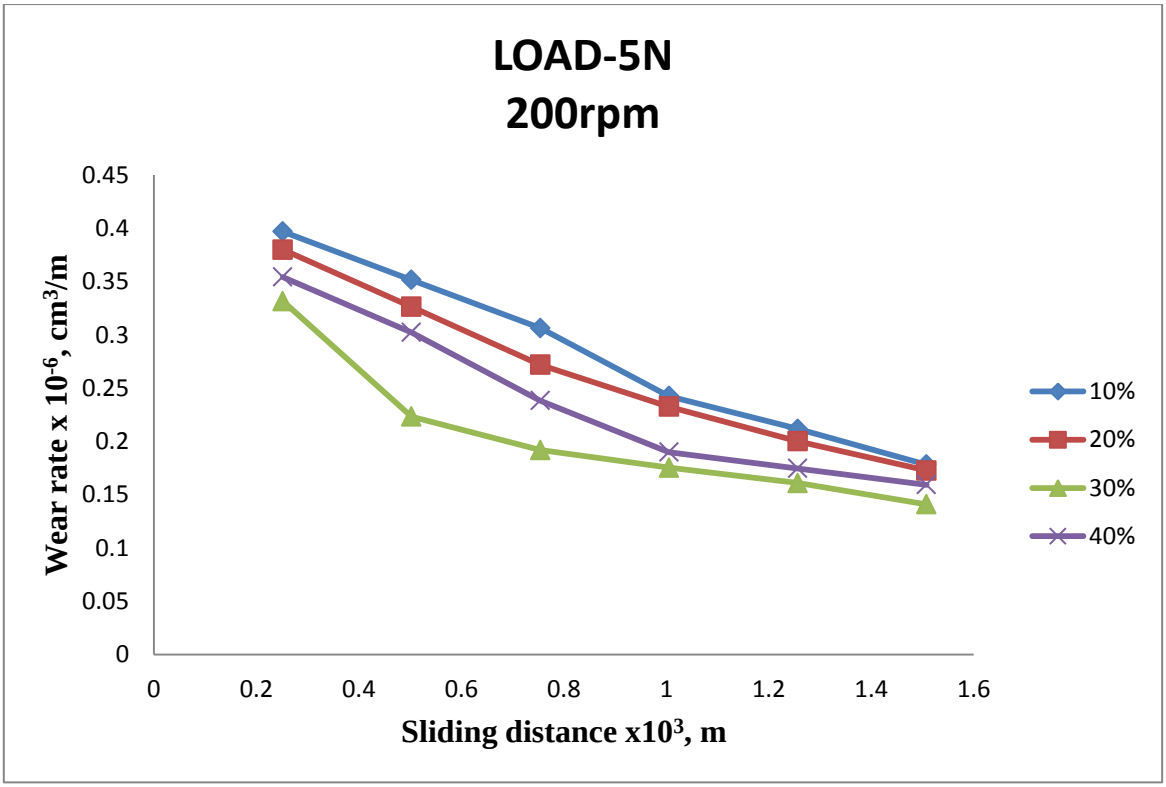

Fig 4.4: Variation of wear rate with sliding distance at 5N load and 200rpm

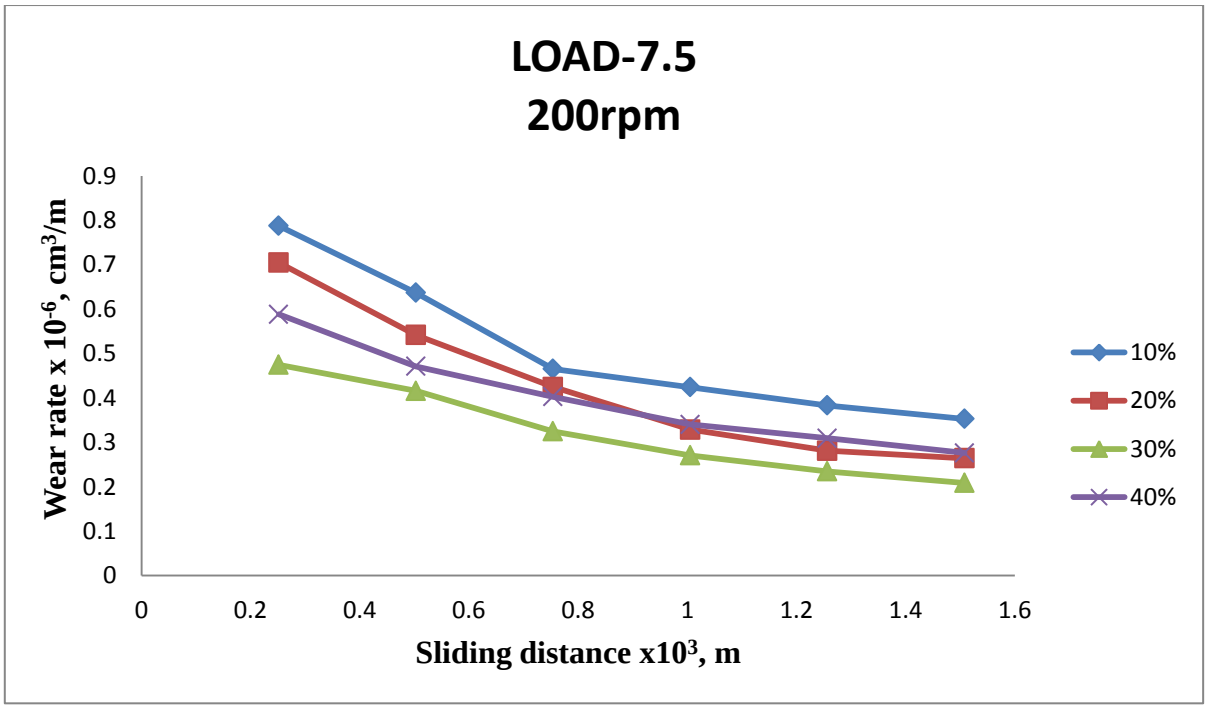

Fig 4.5: Variation of wear rate with sliding distance at 7.5N load and 200rpm

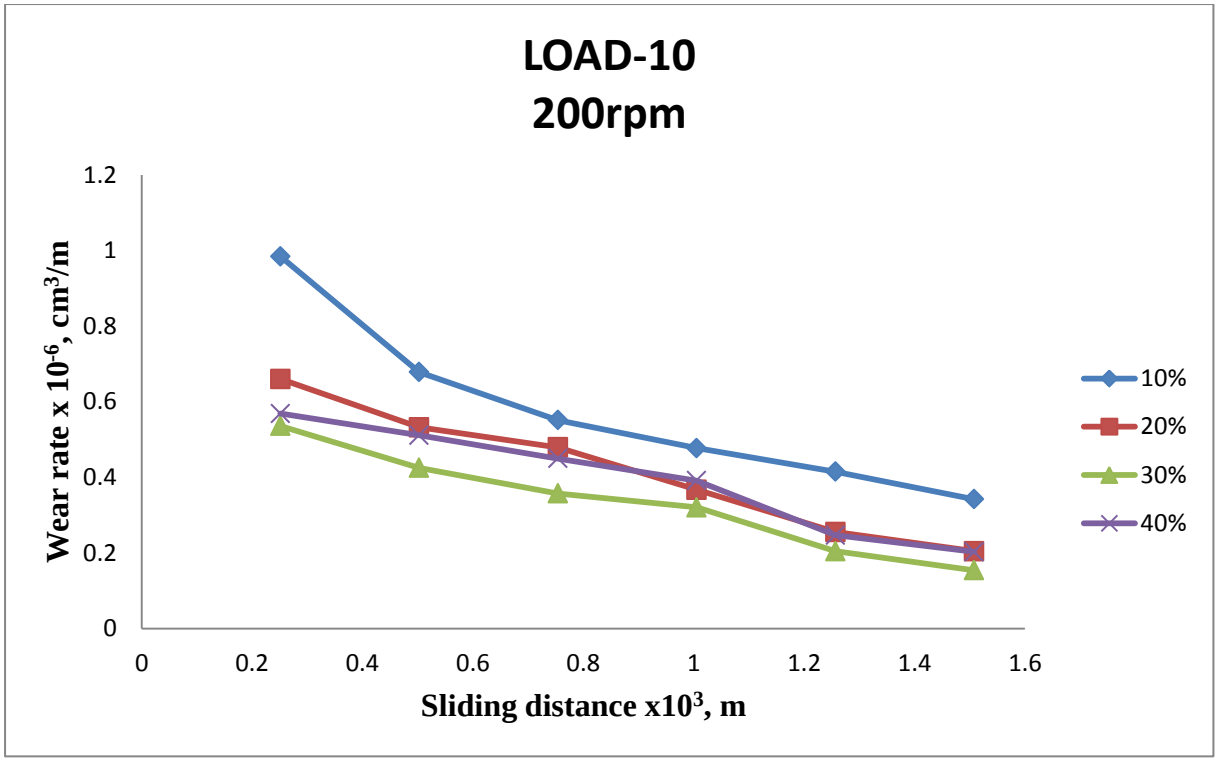

Fig 4.6: Variation of wear rate with sliding distance at 10N load and 200rpm

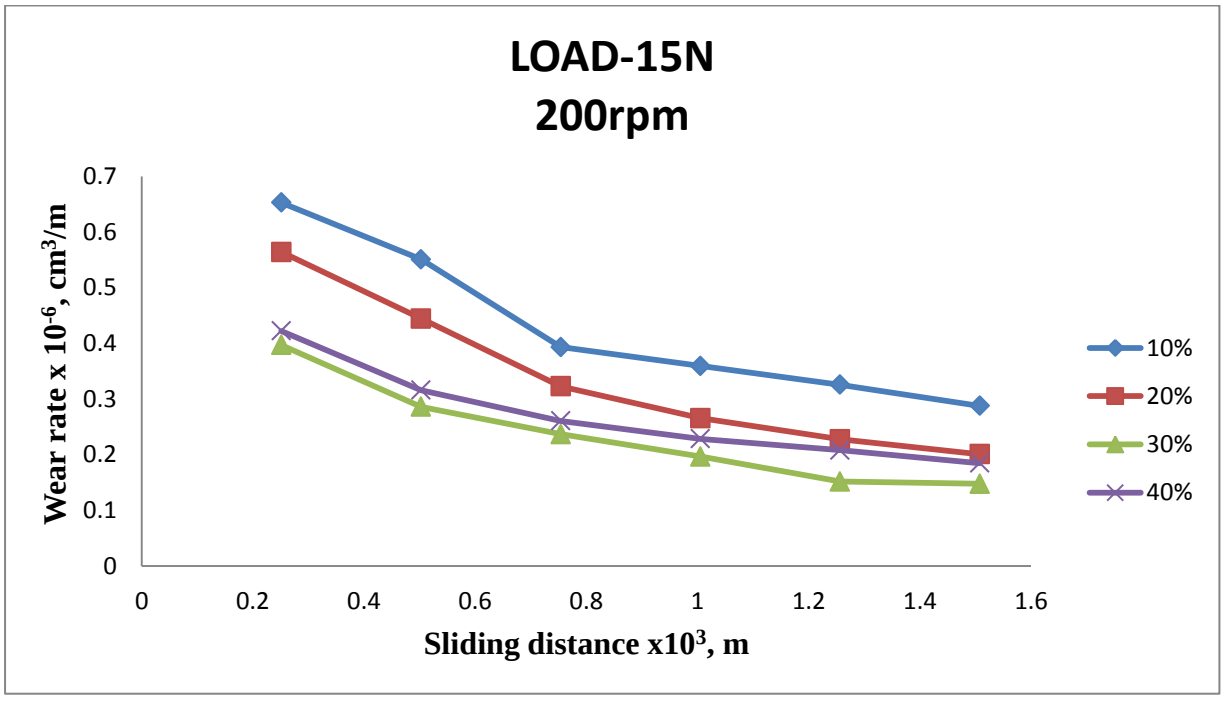

Fig 4.7: Variation of wear rate with sliding distance at 15N load and 200rp

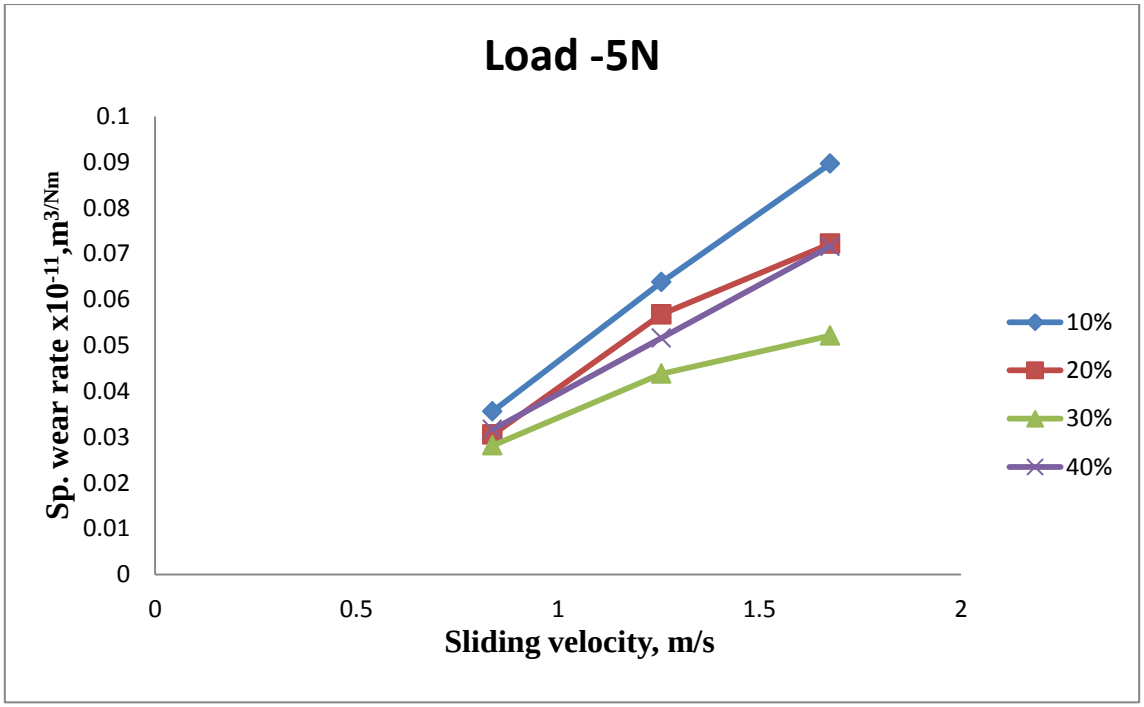

Fig 4.8: Variation of specific wear rate with sliding velocity at 5N load

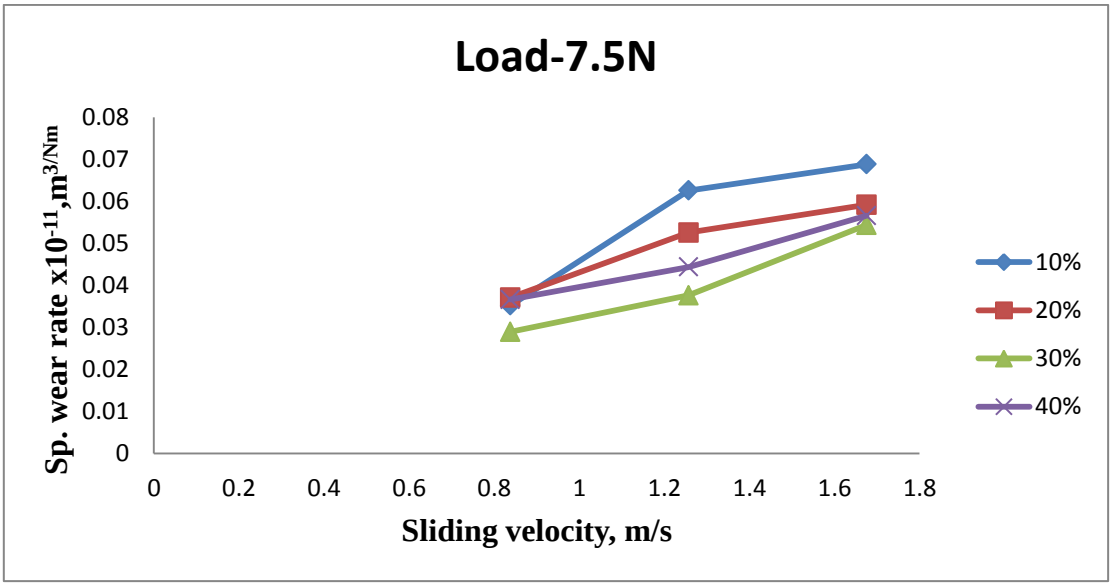

Fig 4.9: Variation of specific wear rate with sliding velocity at 7.5N load

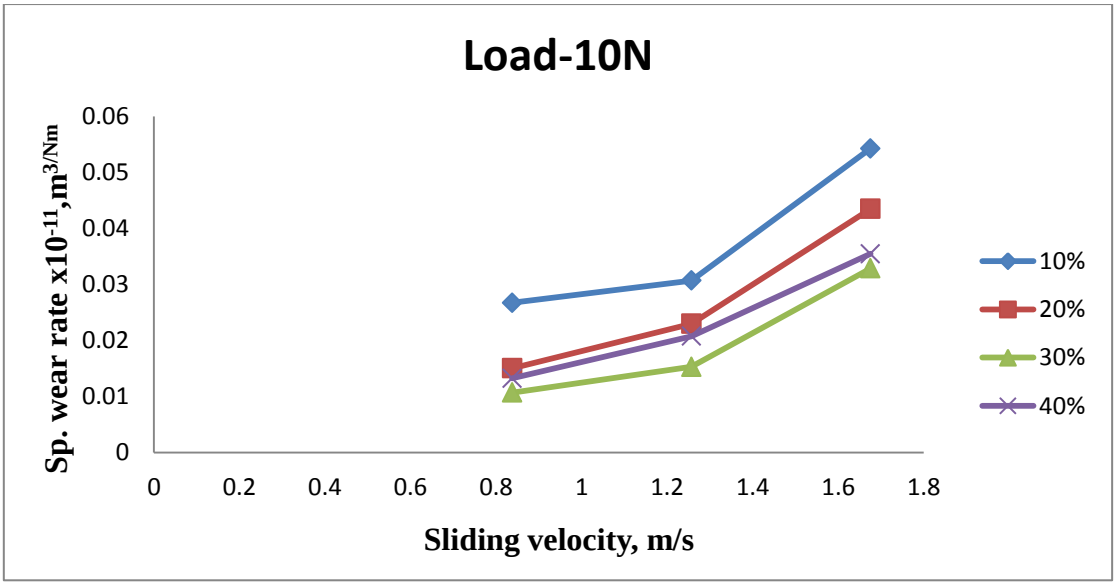

Fig 4.10: Variation of specific wear rate with sliding velocity at 10N load

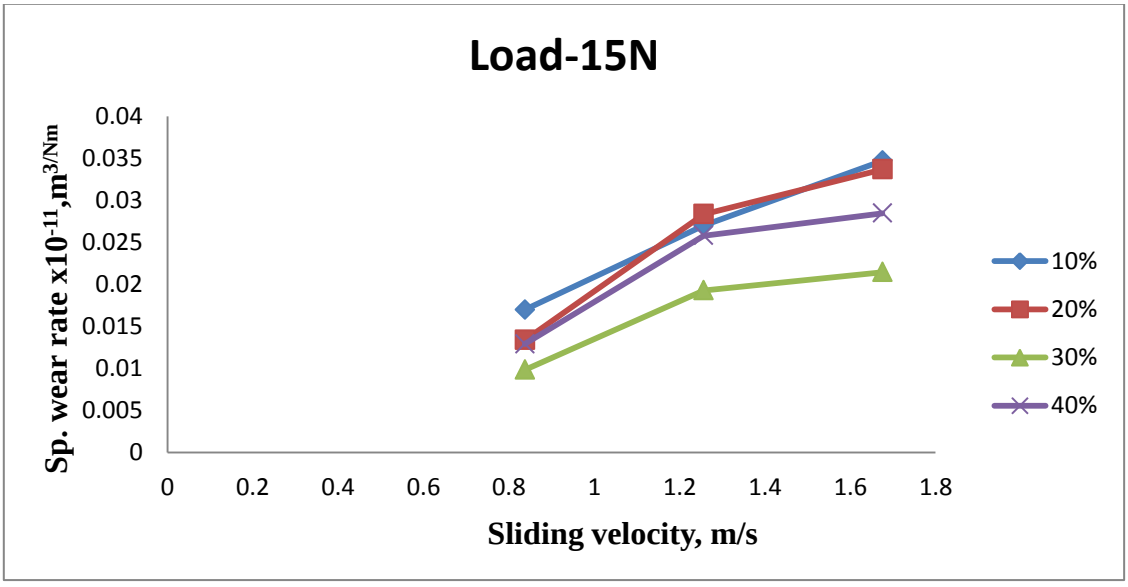

Fig 4.11: Variation of specific wear rate with sliding velocity at 15N load

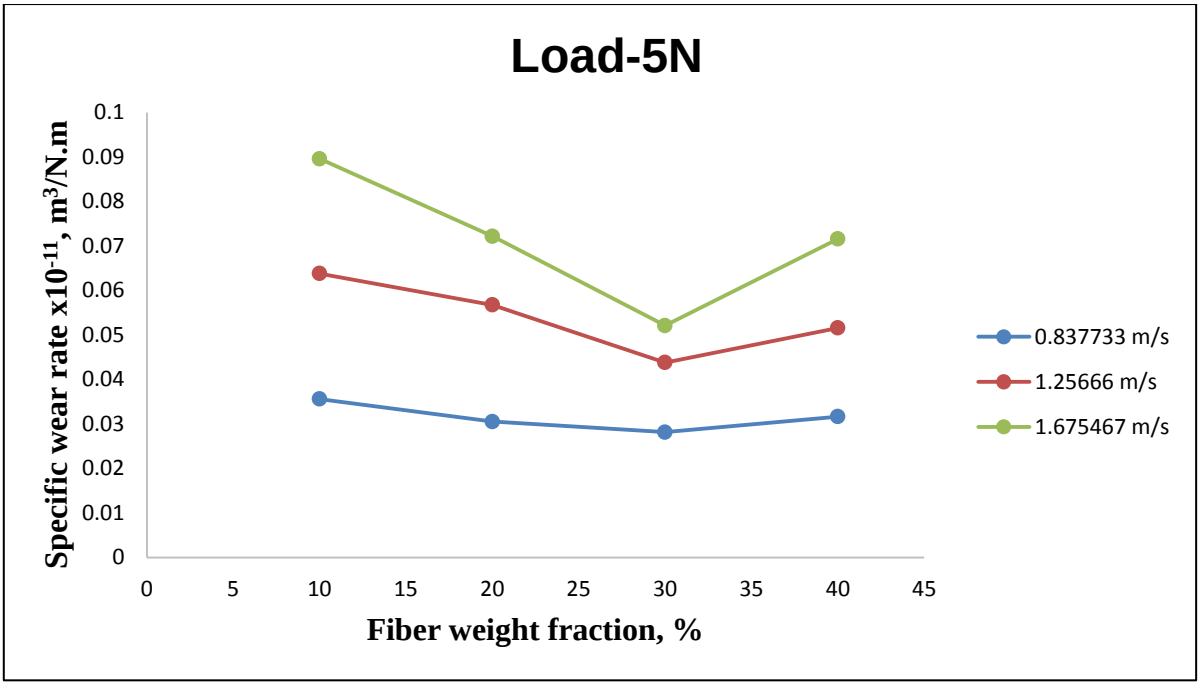

Fig 4.12: Variation of specific wear rate with fiber weight fraction of composite at 5N load

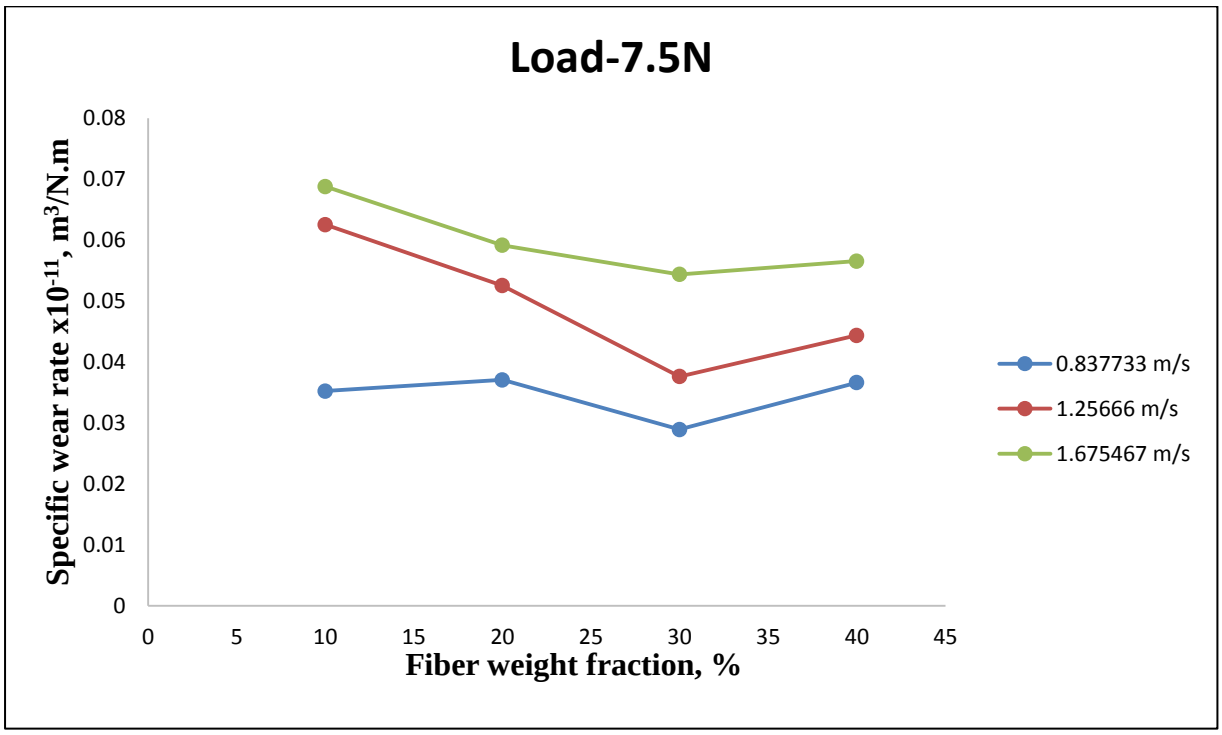

Fig 4.13: Variation of specific wear rate with fiber weight fraction of composite at 7.5N load

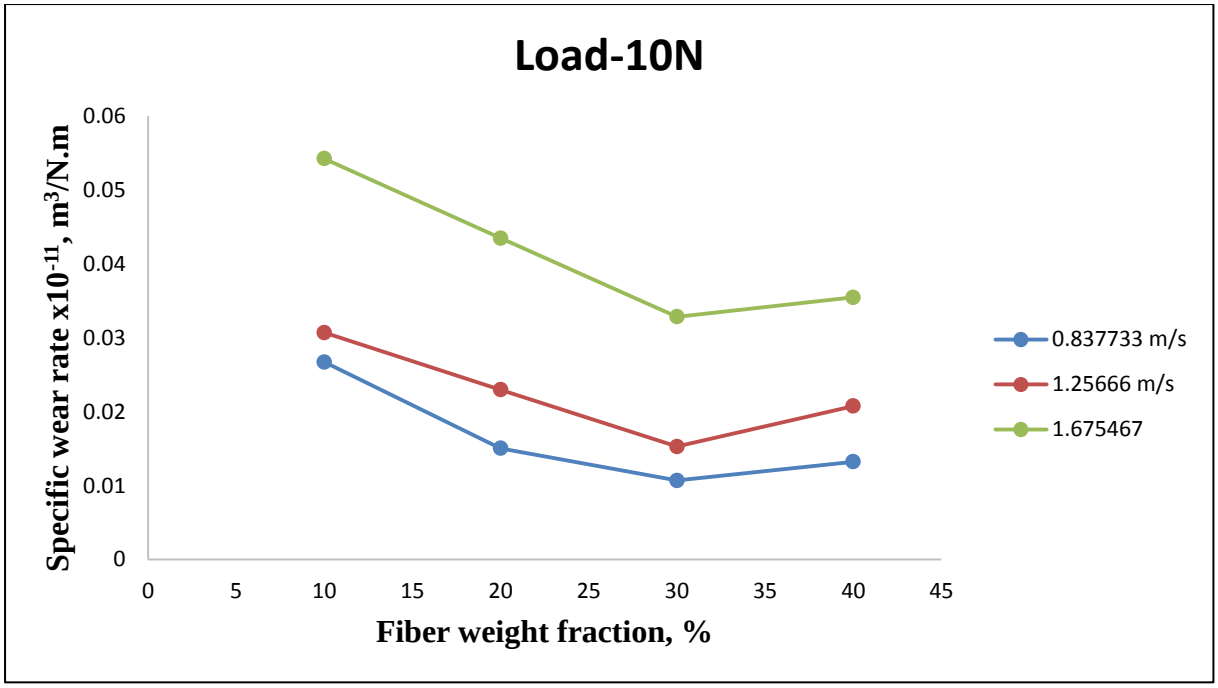

Fig 4.14: Variation of specific wear rate with fiber weight fraction of composite at 10N load

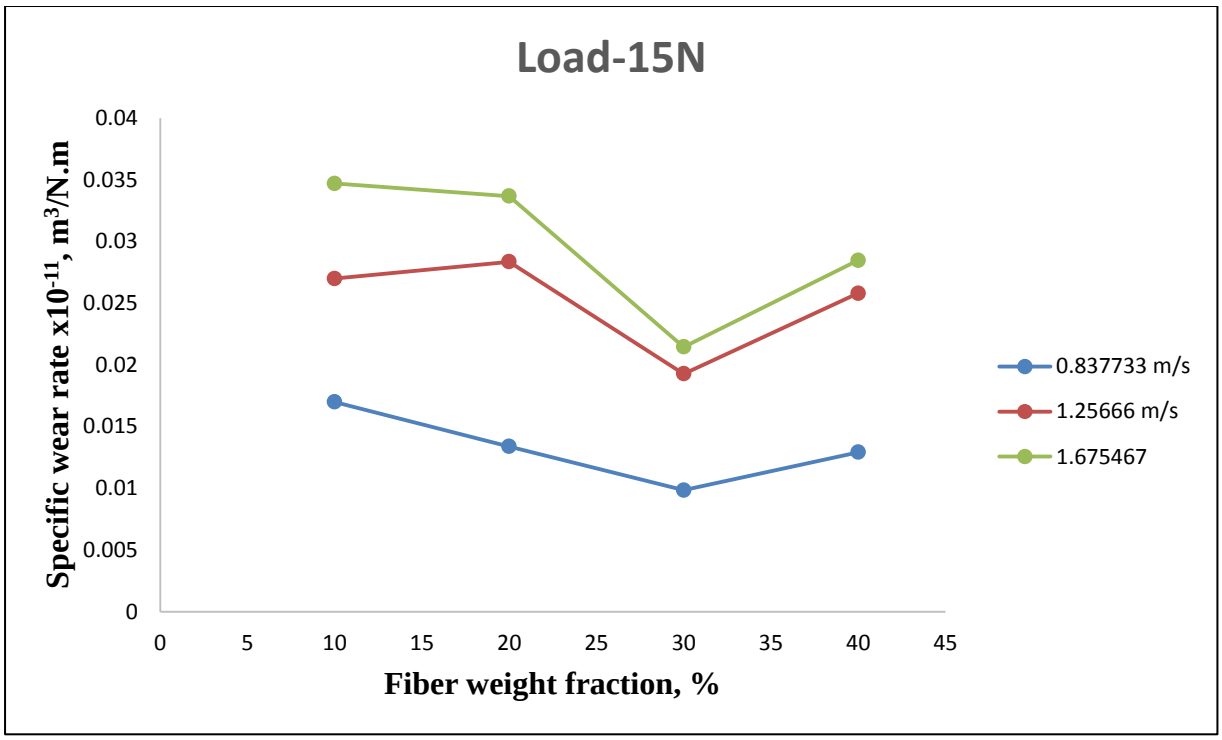

Fig 4.15: Variation of specific wear rate with fiber weight fraction of composite at 15N load

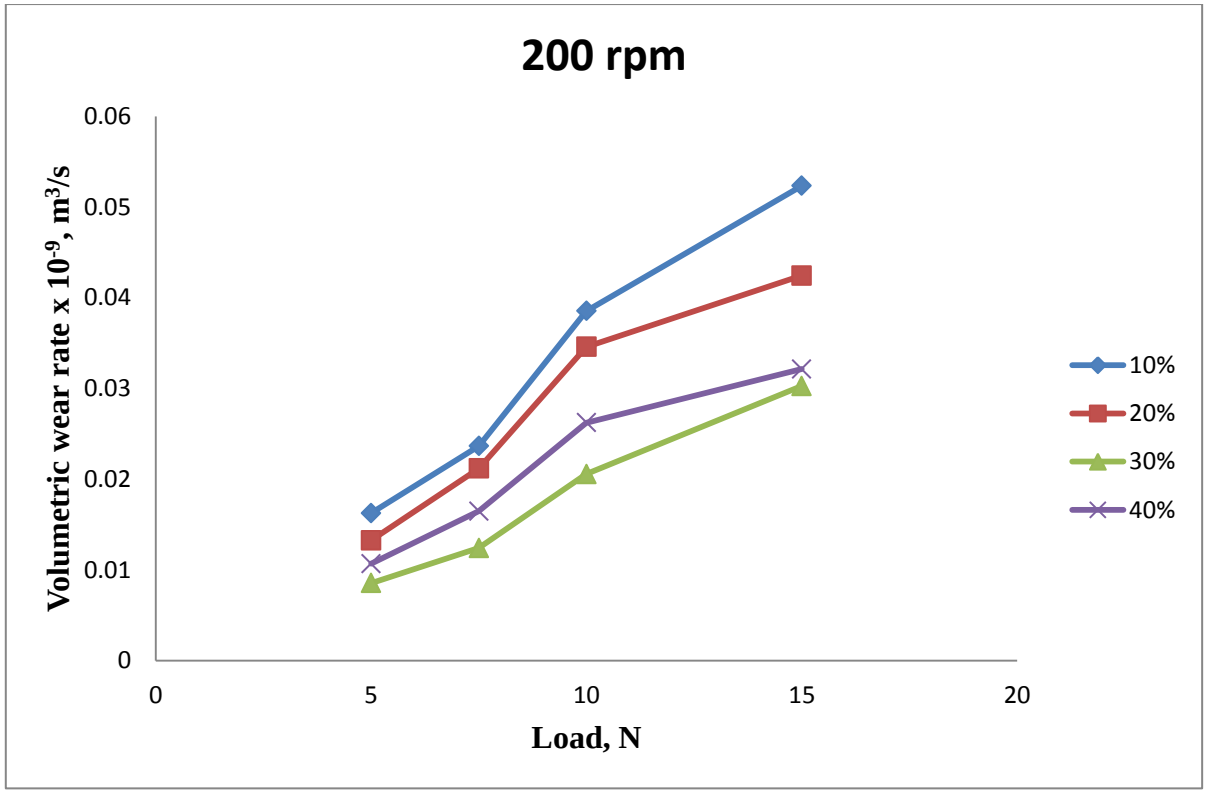

Fig 4.16: Variation of volumetric wear rate with load for all composites at a sliding velocity of 0.8377m/s

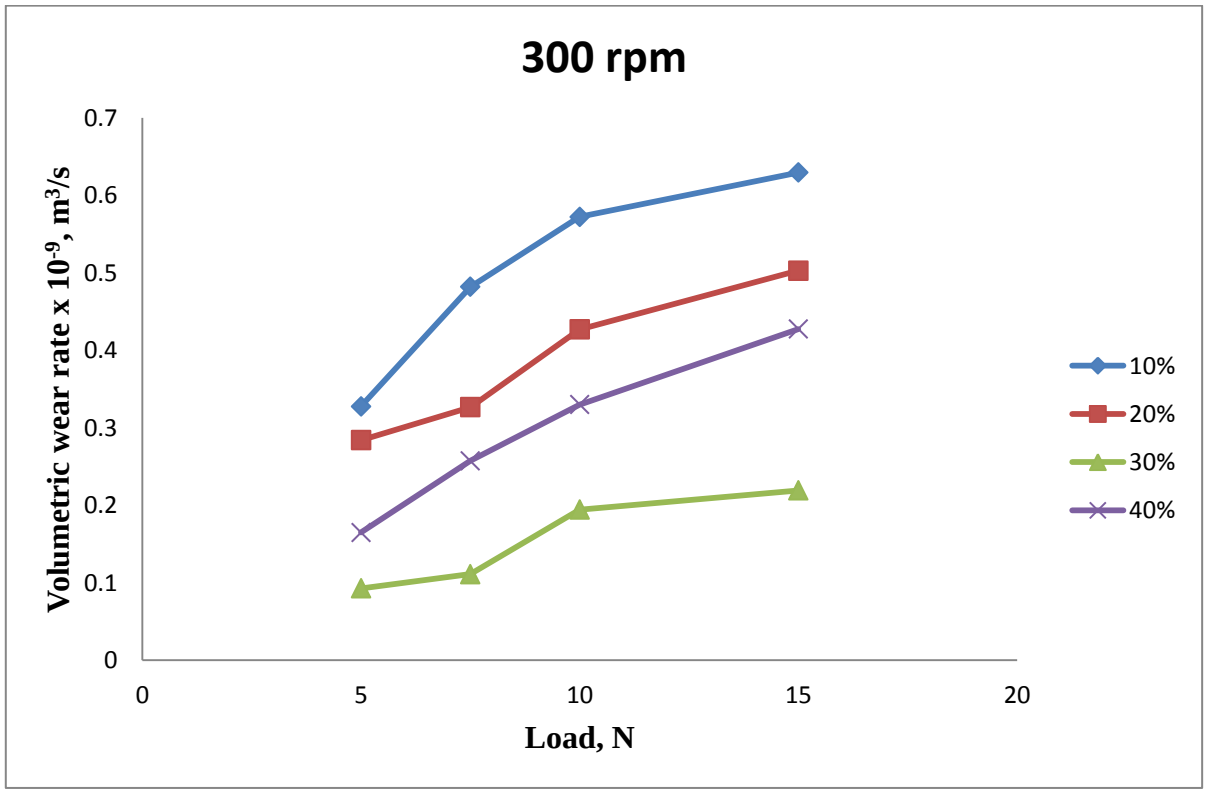

Fig 4.17: Variation of volumetric wear rate with load for all composites at a sliding velocity of 1.2566m/s

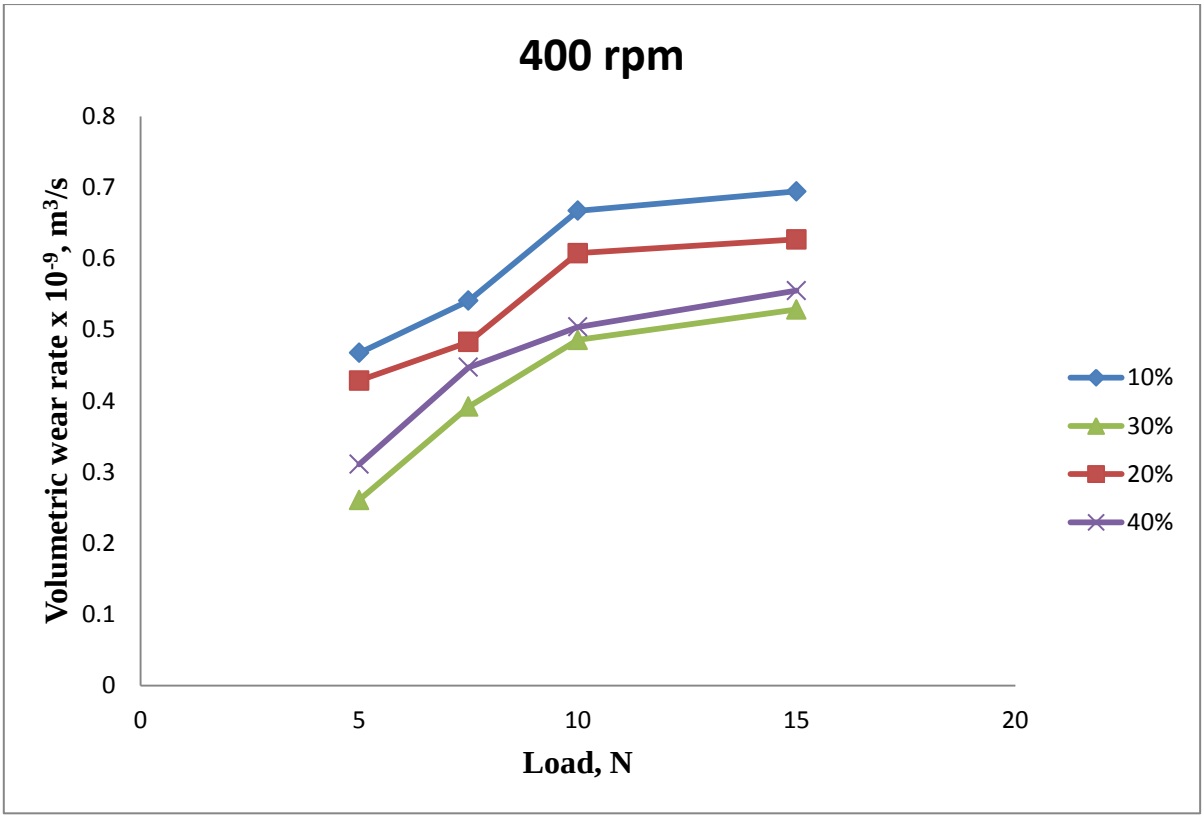

Fig 4.18: Variation of volumetric wear rate with load for all composites at a sliding velocity of 1.6754m/s

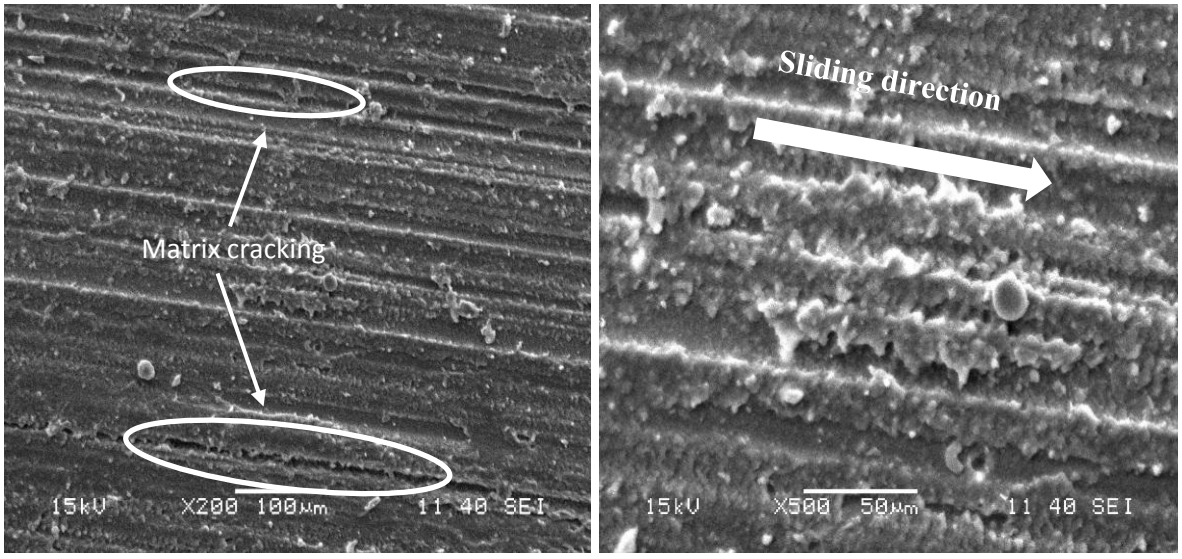

Fig 4.19: (a) abrasive surface after test (b) 30wt% *Ipomoea carnea* reinforced composite under 10N load

Chapter 5

CONCLUSION AND FUTURE WORK

CHAPTER 5

5.1 CONCLUSION:

The following conclusions can be drawn from the experimental studies of *Ipomoea carnea* particulate filled epoxy composite:

1. *Ipomoea carnea* is a well-known weed which is hazardous to animals and its accompanying species. It can successfully be utilised to produce composite by suitably bonding with resin for the development of value added products.
2. The composites prepared were of low density compared to pure epoxy so it can be regarded as a useful light weight material. The density of the composite decreases with the increase of fiber content.
3. On increasing the fiber content the strength and modulus of the composites increases. Thirty volume percentage of reinforcement fiber gives the best combination among the tested specimen.
4. The incorporation of *Ipomoea carnea* into epoxy can significantly reduce abrasive wear loss. The optimum wear resistance property was obtained at a fibre content of 30 per cent weight fraction. However, excessive addition of fiber (40%) results in drawing out of the fiber from the matrix resin during the test due to poor interfacial adhesion.
5. Abrasive wear is very sensitive to normal load compared to sliding velocity and increases marginally with increasing sliding velocity.
6. With increasing sliding distance, wear rate gradually decreases and attains an almost steady state in multi-pass condition.
7. The specific wear rate of the composite decreases with an increase in sliding distance because the space between the abrasive is filled by the debris, which reduces the depth of penetration of abrasive particles into the composite sample.

5.2 RECOMMENDATION FOR FURTHER RESEARCH

1. In the present investigation a hand-lay-up technique was used to fabricate the composite. However there exists other manufacturing process for polymer matrix composite. They could be tried and analysed, so that a final conclusion can be drawn

there from. However the results provided in this thesis can act as a base for the utilization of this fiber.

2. Chemical modification of the fiber with alkali, acetone and benzoyl-chloride may significantly improve the mechanical performance of the composite. Other chemical modification methods such as silane treatment, acetylation treatment, acrylation treatment isocynates treatment, Permanganate treatment, Maleated coupling agents could be tried and a final conclusion can be drawn thereafter.
3. In the current study only dry sliding wear test has been carried out on the untreated *Ipomoea carnea* epoxy composite. The same work could be extended to treated fiber composite.
4. Further different other tribolgical test can also be conducted both for treated and untreated.
5. Carbonization of *Ipomoea carnea* particulate can also done for both both raw and activated particulate, and its influence on mechanical and tribological properties can be studied.

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